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## Impact of Forest Management Techniques on Bats With a Focus on the Endangered Indiana Myotis (Myotis Sodalis)

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IMPACT OF FOREST MANAGEMENT TECHNIQUES ON BATS WITH A FOCUS ON THE  
ENDANGERED INDIANA MYOTIS (*MYOTIS SODALIS*)

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A Thesis

Presented to

The College of Graduate and Professional Studies

Department of Biology

Indiana State University

Terre Haute, Indiana

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

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May 2010

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Keywords: bats, timber, management, Indiana, Midwest

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## ABSTRACT

Understanding how forest management practices impact bats is important for maintaining a diverse bat community; rare species, especially the federally endangered Indiana myotis (*Myotis sodalis*) need special consideration. Bats play an important role in the environment because they prey on insects, especially pest species, and conservation of viable foraging and roosting habitats is critical. Positive and negative aspects of the implementation of forest management techniques are discussed for each bat species. Bats were sampled using mist nets at four locations in Morgan-Monroe and five locations in Yellowwood State Forests twice during each summer 2006-2008. Netting locations were adjacent to or in forest stands scheduled for experimental manipulations following conclusion of netting in 2008. This effort produced 342 bats. These data provide a baseline to understand how bats are affected by long-term forest manipulations. An acoustical survey was conducted in summer 2007 to determine forest habitats where bat species occur. Anabat II bat detectors in four habitat types,--interior forest, canopy gap, forest edge, and corridors--produced calls from 7 species, a total of 3113 calls (842 corridor, 681 forest edge, 1075 canopy gap, and 515 forest interior) during 337 sample nights. Occupancy of each habitat by each species was determined; canopy gaps were occupied most, followed by forest edge, corridors, and interior forest. These data are used to predict the response of bats to forest manipulations.

## PREFACE

## INTRODUCTION TO THE HARDWOODS ECOSYSTEM EXPERIMENT

This study is part of the Hardwoods Ecosystem Experiment (HEE), a joint program between researchers representing Purdue University Department of Forestry & Natural Resources, Indiana Department of Natural Resources (DNR) Division of Forestry, Indiana DNR Division of Fish and Wildlife, Purdue Department of Entomology, Indiana State University Center for North American Bat Research and Conservation, Ball State University Department of Biology, Drake University, and The Nature Conservancy. The goal of HEE is to develop an understanding of how forest management practices (timber harvest and silvicultural practices) impact forests, wildlife, and the public that owns the forests. My responsibility to this larger effort is to obtain baseline data on bat communities prior to harvest. My thesis consists of 3 chapters that provide a baseline for future work in the HEE system and information that will assist bat conservationists in managed forests:

- The first chapter is a literature review of forest management techniques and how those management techniques fit into the life history of bats in the Midwest.
- During 3 field seasons, I completed a comprehensive survey of the bat fauna of Morgan-Monroe State Forest and Yellowwood State Forest, which I supplemented with an older unpublished data set (Brack and Hawkins in Litt). These combined datasets provide a survey of bats of the area, and provide a baseline to which future capture rates can be

compared as forests are manipulated and if resident bat communities are impacted by white nose syndrome (Blehart et al. 2009).

- Numerous studies (Putriquin and Barclay 2003, Owen et al. 2004, Menzel et al. 2005b, Duchamp et al. 2006, Yates and Muzika 2006, Loeb and O'Keefe 2006) have used Anabat II bat detectors to study the distribution of bats across a variety of landscapes; especially landscapes where mist-netting is may be less efficient or known to produce biased samples. I propose to use bat detectors to compare the occupancy of bats using 4 types of forest habitat (interior, edge, corridors, and canopy gaps) in Morgan-Monroe and Yellowwood state forests. In addition to providing insight into the effects of future forest manipulations, these data also provide information about how these habitats are used by bats prior to the emergence of white nose syndrome.

## ACKNOWLEDGMENTS

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## CHAPTER 1

### FOREST MANAGEMENT TECHNIQUES AND BATS OF THE MIDWEST: A REVIEW

The impact of forest management practices on bats is poorly understood, and research has targeted rare species, especially the Indiana myotis (*Myotis sodalis*). Because they prey on insects, including pest species, bats play a critical role in the biological control of insects. Viable foraging and roosting habitats for bat species is integral to maintaining a diverse bat community. This document reviews how bats use forests for roosting and foraging, discusses forest management practices, and identifies how those practices affect bats in the Midwest. Such information is particularly important as bats in the Midwest are increasingly under threat as a new fungal disease, White Nose Syndrome (WNS) approaches from the Northeast.

#### Introduction

Many bat species roost and forage in forested habitats (Barclay and Brigham 1996, Barclay and Kurta 2007). Forest managers face the daunting task of multiple-use management for pulp, pole, and saw timber, habitat for game and nongame wildlife, recreation, protection of biodiversity, carbon sequestration, and protection of waterways and water quality. Bats are a challenge for forest managers despite two volumes (Barclay and Brigham 1996, Barclay and Kurta 2007) addressing relationships between bats and forests. Understanding how bats use forests and how they respond to timber management practices is important (Kurta and Kennedy 2002, Tibbels and Kurta 2003, Miller 2003, Fisher and Wilkinson 2005). This document reviews impacts of forest management practices on bats, how bats use forests, provide a synopsis of basic

timber management techniques, and reviews case studies that examine the response of bats to these practices. Finally, I hypothesize how forest management techniques affect species of bats in the Midwestern United States (U.S.) (i.e., U.S. Fish and Wildlife service Region 3; Figure 1).



Figure 1. Midwestern United States (Region 3 of the U.S. Fish and Wildlife Service). Iowa = IA, Illinois = IL, Indiana = IN, Michigan = MI, Minnesota = MN, Missouri = MO, Ohio = OH, Wisconsin = WI.

### How Do Bats Use Forests?

#### *Roosting*

Twenty-seven of 45 species of bats in North America and 11 of 14 species in the Midwestern U.S. roost in trees at least during the maternity season (Lacki et al. 2007). Tree roosting habitats are of 2 types: cavities or under the bark of dead and dying trees, and foliage.

Cavity and bark roosting bats tend to use dead (snags), dying (green snags), or hollow trees as roosts. Roosting in cavities and under bark facilitates energy conservation, growth of young, and predator protection (Lacki et al. 2007). These bats tend to live in larger groups and when individuals excluded from a primary roost form smaller groups, they often experience lower reproductive success (Brigham and Fenton 1986). Species of bats that use cavities or bark include most species of *Myotis*, evening (*Nycticeius humeralis*), Rafinesque's big-eared (*Corynorhinus rafinesquii*), silver-haired (*Lasionycteris noctivagans*) (Novakowski 1956), and big brown (*Eptesicus fuscus*) bats (Barclay and Kurta 2007).

Tree or foliage-roosting bats live in the tree canopy and tend to be solitary or form small colonies (Lacki et al. 2007). The lasiurines (Genus *Lasiurus*) roost on limbs among foliage. Pregnant and lactating females roost in the upper canopy, but males and nonreproductive females often roost in the understory or even under leaf litter (Mager and Nelson 2001). The eastern pipistrelle (*Perimyotis subflavus*) roosts in clumps of dead leaves (Veilleux et al. 2003, Yates and Muzika 2006).

Typically, tree-roosting bats change roosts every few days for reasons that remain poorly understood but which may include access to new foraging grounds, access to better roost microclimates, to gain knowledge of alternate roosts in case the primary roost is lost, and a reduction in parasite loads (Lewis 1996, Lacki 2007). Species that inhabit more temporary roosts switch roosts more frequently than species that inhabit caves and buildings (Lewis 1996).

### *Foraging*

Forested habitats provide foraging and commuting habitat for bats. Depending on the species, bats may forage in corridors and openings within the forest, in the interior of the forest, or at edges between the forest and open areas. Foliar surfaces above and below the canopy may

also be used. Forest structure, particularly vegetative clutter, is an important factor in determining which habitats are used by bats (Loeb and O'Keefe 2006). Larger bats with low-frequency echolocation calls tend to forage in more open habitat while smaller bats using a higher call frequency can maneuver better in clutter (Brooks and Ford 2005).

Bats in the Midwest eat a variety of insects including silvacultural and crop pests (Whitaker and Hamilton 1998). Dietary preferences of bats, the habitats used by insect prey, and insect responses to temporal changes (seasonal, lunar cycles, and daily) affect where bats forage (Lacki et al 2007). Finally, free water can be limiting in dry climates (Barbour and Davis 1969), and although drinking water is often readily available in the Midwest (Kurta 2005), standing water may be sparse in areas of high relief during lactation and early volancy of young, when demand may be greatest.

## Forest Management Practices

### *Introduction*

Forest management and timber harvest techniques include single-tree, shelter-wood, group, and clear cuts, depending on the type of forest and goals of the land owner. Once harvested, managers use a variety of techniques to regenerate (re-establish) forests, including natural reseeding in shelter-wood and seed-tree harvests, resprouting of harvested stock from roots or stumps (coppice sprouts), prescribed fire, and planting of seedlings (Lacki et al. 2007). As new stands develop, managers may allow succession to proceed uninterrupted or use techniques like prescribed fire and timber stand improvement (killing undesirable trees and vines) to direct and speed succession toward a targeted seral stage.

Each forest has unique edaphic, light, and climate conditions under which implementation of the same management techniques produce different spatial and temporal

results. These differences, along with human use, consumptive (e.g. roads) and non-consumptive (e.g., nature watching and hiking), of the forest affect the end product of management practices in the Midwest.

### *Even-aged*

Even-aged timber management refers to use of clear or shelter-wood cuts to produce stands of a uniform age. Tree harvest removes potential roost trees; however, harvest also creates less cluttered foraging habitats. Small maneuverable bats such as the Indiana myotis (*Myotis sodalis*) and Northern myotis (*Myotis septentrionalis*) tend to forage along edges of clear cuts (Grindal 1996) into forest interiors, while open areas, i.e. centers of clear cuts and larger corridors, are used by larger, faster flying, long-winged species like big brown bat and eastern red bat (*Lasiurus borealis*) (Hogburg et al. 2002, Putriquin and Barclay 2003, Owen et al. 2004). In pre-European settlement forests dominated by shifting mosaics of species, canopy gaps provided foraging habitat for both large and small bats (Fisher and Wilkinson 2005). Even-aged cuts may create roosts for bark/cavity dwelling bats when trees are girdled or damaged; foliage roosting bats lose roosts in large clear cuts where all trees are removed.

### *Uneven-aged*

Uneven-aged timber management refers to single-tree or small-group selection (removal) to produce a forest with a mosaic of ages. The impact of these cuts is difficult to ascertain because of their small size. There is little empirical evidence upon which to evaluate the negative or positive impact on bats. Short-term, single tree selection may produce small areas of uncluttered habitat in an otherwise cluttered habitat, improving foraging habitat for species that forage in the open (Lacki et al. 2007). The effect of uneven-aged cuts on roost availability is analogous with even-aged cuts, but on a smaller scale.



### *Prescribed Fire*

Prescribed fire affects bat roosts and foraging habitats. Prescribed fire is used to 1) provide habitat for wildlife, 2) remove understory vegetation, and 3) improve regeneration of oak (*Quercus*) and hickory (*Carya*) species. Forests in the Midwest have been largely fire-free for the last 100 years (Pierce et al 2006), but fire has recently become a common tool in managed forests. Prescribed burns may alter the quantity and quality of roosts, modify foraging habitat, and increase prey abundance (Carter et al. 2000, Boyles and Aubrey 2005). Bark and cavity roosting bats tend to be extensively affected by fire; large fires may destroy snags while smaller fires may create snags (Boyles and Aubrey 2005). In Red River Gorge and Daniel Boone National Forest, Kentucky areas subjected to prescribed burn had more roosts than unburned areas (Lacki et al. 2009), suggesting that prescribed fires benefit bats that roost in snags. Foliage roosting bats are affected by prescribed burns if they roost on the ground in cold weather. Red bats that roost in leaf litter (Boyles and Aubrey 2005) and evening bats in underground roosts (Boyles et al. 2005) during winter may be killed by fires. To minimize losses of these bats, prescribe fires should be set during warmer days when bats are not in the leaf litter. Removal of fire-intolerant, understory trees may produce a less cluttered foraging habitat benefiting species that cannot forage in a cluttered forest.

### *Timber Stand Improvement*

Timber stand improvement (TSI) is used to promote growth of desired tree species and typically includes use of mechanical removal or herbicide to kill shrubs and vines and girdling of less desirable trees. These actions may impact bats in two ways: Removal of the understory reduces clutter benefiting bats that cannot forage in clutter, and they may create snags that provide roost sites (Whitaker et al. 2005, Boyels and Aubrey 2005).

### *Other Timber Harvest Impacts*

Timber harvests impact more than trees. Forest management requires equipment and men that enter and exit the forests and there are facilities of various kinds. In short, roads and trails, utility corridors, buildings, and other structures are needed. Roads, trails, and corridors often provide fly-ways for bats, and thus are productive sites for bat capture (Limpens et al. 1989, Zimmerman and Glanz 2000, Brown and Brack 2003, Kiser and MacGregor 2005). Buildings provide roosts for some species of bats, but large-scale developments may destroy natural roosts. Staging areas and clearings for buildings may provide foraging habitat for bats that do not tolerate clutter. Water sources and soil structure are also affected. Creation of water sources such as woodland ponds provides habitat for many species of flora and fauna and allows bats access to drinking water and insect prey (Kiser 2005). An arrangement that may especially benefit bats is to place ponds at the intersection of multiple habitat types. Even deep road ruts in upland areas can hold rain water and be important water source for bats (Krusac and Mighton 2002). During timber harvest, forest soils may be compacted by heavy machinery, which may reduce the availability of ground roosts for hibernating bats (Boyles and Aubrey 2005).

### Specific Management Practices for Bat Species

For each species of bat, and for each timber management practice, two related issues must be addressed: (1) what roosting and foraging habitats are used (Lacki et al. 2007), and (2) what are the short and long term effects of the management activity on roosts and foraging habitats.

A management strategy to benefits all bats will likely require an array of management techniques. A lack of active timber management is one option, but it is itself a type of management that will favor some species over others (Lacki et al. 2007). Using management

techniques that increase the number of habitat types and produce a more diverse landscape should yield a greater bat species diversity. A specific type of management may benefit a species over the short-term but have a negative impact in the long-term. A continuum of habitats, in time and space, is likely to provide the best long-term solution. The following sections discuss management techniques for individual species (Table 1.)

Table 1. Effect, by species, on summer foraging and roosting habitat resulting from timber management practices, strongly positive (++), positive (+), strongly negative (--), negative (-), unknown (U), and marginally affected/unaffected (\*). All timber management applications are described in the Hardwood Ecosystem Experiment over view (Appendix A).

Species	Foraging - Short Term (0-40 years, after cut to when subcanopy is cluttered <sup>1</sup> )				Comments
	Even-aged		Uneven-aged		
	Clear Cut (< 10 acres)	Shelter-wood	Small-Group Selection	Single- Tree Selection	
<i>Myotis sodalis</i>	++	++	+	*	Forages along edges, with reduced clutter, and over saplings.
<i>Myotis grisescens</i>	-	U/*	*	*	Forages over aquatic habitats and associated riparian woodlands.
<i>Lasiurus borealis</i>	++	++	+	*	Forages in large openings, with no clutter, and over saplings.
<i>Myotis septentrionalis</i>	-	*/U	*	*	Forages in most habitats and can tolerate clutter.
<i>Eptesicus fuscus</i>	++	+	+	*	Forages in large openings, with no clutter, and over saplings.
<i>Myotis lucifugus</i>	++	+	+	*	Forages along edges with reduced clutter.
<i>Perimyotis subflavus</i>	*	*	*	*	Forages in most habitats and can tolerate clutter.
<i>Lasiurus cinereus</i>	++	+	*	*	Forages in large openings and above canopy.
<i>Lasionycteris noctivagans</i>	+	+	+	*	Forages along edges with reduced clutter.
<i>Nycticeius humeralis</i>	+	+	+	+	Forages in openings and above canopy
<i>Corynorhinus rafinesquii</i>	+	+	+	*	Forages in cluttered forest and in intact forest.
<i>Corynorhinus townsendii</i>	++	+	+	*	Forages in large openings, edges, with no clutter, and over saplings.
<i>Myotis leibii</i>	+/U	+/U	U/+	U/+	May be similar to other <i>myotis</i> .
<i>Myotis austroriparius</i>	U/+	U/+	U/+	U/*	May be similar to other <i>myotis</i> .

Table 1. (cont.)

Species	Foraging - Long Term (80-800 years, maturation of forest leading to shifting mosaic forest <sup>2</sup> )				Comments
	Even-aged		Uneven-aged		
	Clear Cut (< 10 acres)	Shelter-wood	Small-Group Selection	Single- Tree Selection	
<i>Myotis sodalis</i>	--	-	*	*	Cluttered stands impede foraging.
<i>Myotis grisescens</i>	+	+	*	*	Cluttered stands impede foraging.
<i>Lasiurus borealis</i>	--	--	-	*	Cluttered stands impede foraging.
<i>Myotis septentrionalis</i>	*	*	*	*	Tolerates clutter.
<i>Eptesicus fuscus</i>	--	--	-	*	Cluttered stands impede foraging.
<i>Myotis lucifugus</i>	-	-	-	*	Cluttered stands impede foraging.
<i>Perimyotis subflavus</i>	*	*	*	*	Tolerates clutter.
<i>Lasiurus cinereus</i>	--	--	-	*	Cluttered stands impede foraging.
<i>Lasionycteris noctivagans</i>	-	-	-	*	Cluttered stands impede foraging.
<i>Nycticeius humeralis</i>	--	-	-	*	Cluttered stands impede foraging.
<i>Corynorhinus rafinesquii</i>	*	*	*	U/*	Tolerates clutter.
<i>Corynorhinus townsendii</i>	--	--	-	*	Cluttered stands impede foraging.
<i>Myotis leibii</i>	U/-	U/-	U/-	U/*	May be similar to other <i>myotis</i> .
<i>Myotis austroriparius</i>	U/-	U/-	U/-	U/*	May be similar to other <i>myotis</i> .

Table 1. (cont.)

Species	Roosting - Short Term (0-40 years, after cut to when subcanopy is cluttered <sup>3</sup> )				Comments
	Even-aged		Uneven-aged		
	Clear Cut (< 10 acres)	Shelter-wood	Small-Group Selection	Single- Tree Selection	
<i>Myotis sodalis</i>	-	+	+	+/*	Creation of snags is beneficial.
<i>Myotis grisescens</i>	*	*	*	*	Roost in caves.
<i>Lasiurus borealis</i>	-	*	*	*	Loss of roosts with timber harvest will have a negative effect but roosts are still available.
<i>Myotis septentrionalis</i>	-	+	+	+	Creation of snags is beneficial.
<i>Eptesicus fuscus</i>	-/*	-/*	*	*	Roosts mostly in anthropomorphic structures and tree cavities.
<i>Myotis lucifugus</i>	-	+	+	+/*	Roost mostly in anthropomorphic structures and tree cavities.
<i>Perimyotis subflavus</i>	-	-	*	*	Loss of roosts with timber harvest will have a negative effect but roosts will still be available.
<i>Lasiurus cinereus</i>	-	-	*	*	Loss of roosts with timber harvest will have a negative effect, needs tall mature trees as roosts.
<i>Lasionycteris noctivagans</i>	-	-	*	*	Roost in tree cavities but unknown if other roost types are used.
<i>Nycticeius humeralis</i>	-	-	*	*	Roost in tree cavities, under bark, and anthropomorphic structures.
<i>Corynorhinus rafinesquii</i>	-	-	*	*	Roost in tree cavities, caves, and anthropomorphic structures.
<i>Corynorhinus townsendii</i>	*	*	*	*	Roost in caves and anthropomorphic structures.
<i>Myotis leibii</i>	*	*	*	*	Roost in rock crevices and anthropomorphic structures.
<i>Myotis austroriparius</i>	U/-	U/+	U/+	U/*	Roost in caves, buildings, and hollow trees.

Table 1. (cont.)

Species	Roosting - Long Term (80-800 years, maturation of forest leading to shifting mosaic forest <sup>2</sup> )				Comments
	Even-aged		Uneven-aged		
	Clear Cut (< 10 acres)	Shelter-wood	Small-Group Selection	Single- Tree Selection	
<i>Myotis sodalis</i>	+	+	*	*	Negative effect without creation of new snags or regeneration of suitable roost trees.
<i>Myotis grisescens</i>	*	*	*	*	Roost in caves.
<i>Lasiurus borealis</i>	+	+	+	*	Roosts in foliage.
<i>Myotis septentrionalis</i>	+	+	*	*	Negative effect without creation of new snags.
<i>Eptesicus fuscus</i>	*	*	*	*	Roost mostly in anthropomorphic structures but older trees will provide more tree cavities.
<i>Myotis lucifugus</i>	+	+	*	*	Roost mostly in anthropomorphic structures but older trees will provide more tree cavities.
<i>Perimyotis subflavus</i>	+	+	+	+	Roosts in foliage and buildings.
<i>Lasiurus cinereus</i>	+	+	*	*	Roosts in foliage.
<i>Lasionycteris noctivagans</i>	+	+	*	*	Roost in tree cavities, but unknown if other roost types are used.
<i>Nycticeius humeralis</i>	+	+	*	*	Roost mostly in anthropomorphic structures but older trees will provide more tree cavities.
<i>Corynorhinus rafinesquii</i>	+	+	*	*	Roost mostly in anthropomorphic structures but older trees will provide more tree cavities.
<i>Corynorhinus townsendii</i>	*	*	*	*	Roost in caves and anthropomorphic structures
<i>Myotis leibii</i>	*	*	*	*	Roost in caves and anthropomorphic structures.
<i>Myotis austroriparius</i>	U/+	U/+	U/*	U/*	Roost in caves, buildings, and hollow trees.

<sup>1</sup> 40-80 years, Dense stands of timber lacking corridors and openings is a foraging barrier to all bat species, with a strong negative effect.

<sup>2</sup> > 800 years, Shifting mosaic forests are collection of all the forest's successional stages and may resemble timber managed by Native Americans, which have not existed since European occupation and likely drove the evolution of all bats in the Midwest. Shifting mosaic stands will have a strongly positive effect on all bat species.

<sup>3</sup> 40-80 years, Roosts availability in young to mature forests will be scarce for most bark/cavity roosting bats and foliage roosting species that require large trees.

### Indiana Myotis (*Myotis sodalis*)

Because the Indiana myotis (*Myotis sodalis*) is a U.S. federally endangered species, it is of particular interest to forest managers. During summer, both males (Gumbert et al. 2002) and females (Kurta 2005) live primarily under the exfoliating bark of dead and live trees. Maternity colonies use larger trees than individual males (Kurta 2005). Indiana myotis often move among primary and alternate roosts in both live and dead trees (Humphrey et al. 1977, Callahan et al. 1997, Kurta 2005, Whitaker and Sparks 2008). Shag (*Carya ovata*) and shell (*C. lacinosa*) bark hickories are often used as both alternate and primary roosts (Callahan et al. 1997, Kurta 2005, Whitaker and Sparks 2008). Oaks, cottonwoods, and ashes are other species commonly used as roosts. Forest habitats are extensively used by Indiana myotis foraging at an air/foilage interface such as above and below the canopy, logging roads, riparian streams, small forest fragments, large blocks of forest, and along the edges of clear cuts (Brack in press, Sparks et al. 2005, Menzel et al. 2001).

### *Management*

In forested areas, retention of snags with exfoliating bark provides valuable roosts. Indiana bats benefit from forestry practices that encourage a steady supply of large dead trees (Carter and Feldhammer 2006). For example, in Indiana, Indiana myotis occupied trees girdled and left standing as part of a timber stand improvement (Brack and Whitaker 2006). Because they roost in both shag and shell bark hickories, silvicultural practices that encourage growth and retention (especially after death) of these species are valuable. Oaks in uplands and cotton woods and ash (spp.) in bottomlands are also particularly valuable roost trees (Callahan et al. 1997) because the bark often stays attached to these trees for several years after they die. Indiana myotis occasionally uses artificial roosts, including bat boxes, “skirted” telephone poles, and



even under the siding of homes (Sparks et al. 2009, Whitaker et al. 2006). While, large-scale provisioning of artificial roosts for this species has limited justification (Whitaker et al 2006, Sparks et al. 2009), use of artificial roosts may be justified as part of a collective habitat management and enhancement effort where natural roosts are limited, such as in young forests.

This bat forages in many types of wooded lands, making extensive use of edges and riparian zones. As such, in large areas of unbroken forest, this species will benefit from openings caused by clear cuts, prescribed fires, thinning procedures, and small access roads that provide access (Krusac and Mighton 2002) to and from foraging habitat. Clear cuts create edge habitat within the forest used while foraging and they encourage regeneration of oaks and hickories for future roosts if they are not too small. Prescribed fire can reduce clutter and create snags, and it encourages regeneration of oak and hickory trees that provide future roosts. Thinning procedures such as shelter-wood cuts eliminate the subcanopy, reducing clutter and allowing movement through the forest. Indiana myotis foraged above young saplings at the Indianapolis International Airport (Sheets In Litt.), indicating young regenerating forests and shrubby areas provide high quality foraging habitat.

A visual representation of how timber management practices effect the quality of Indiana myotis summer foraging habitat through time is included (Figure 2). The quality of foraging habitat is largely independent of the size of the timber cut. Clear cuts, shelter-woods, and single tree/group selections can be different in size, but seem to have the same quality of habitat if they consist of uncluttered space surrounded by forest edge. There are exceptions such as single tree selection openings, which may be too small to forage in unless they are connected by a corridor. Indiana myotis summer foraging habitat quality is excellent when a disturbance (clear cut) creates an opening within a forest. The foraging habitat quality decreases as tree clutter

increases. Through time the forest structure naturally decreases clutter, eventually providing more small openings resembling single tree/group harvests. Shelter-wood understory cuts mimic the horizontal diversification stage of forest succession until the over story is cut, when succession will essentially “jump” in successional time to a clear cut with saplings; both of which are high quality foraging habitats. TSI and prescribed fire, by decreasing forest clutter, will set the successional time line forward or backward, respectively.

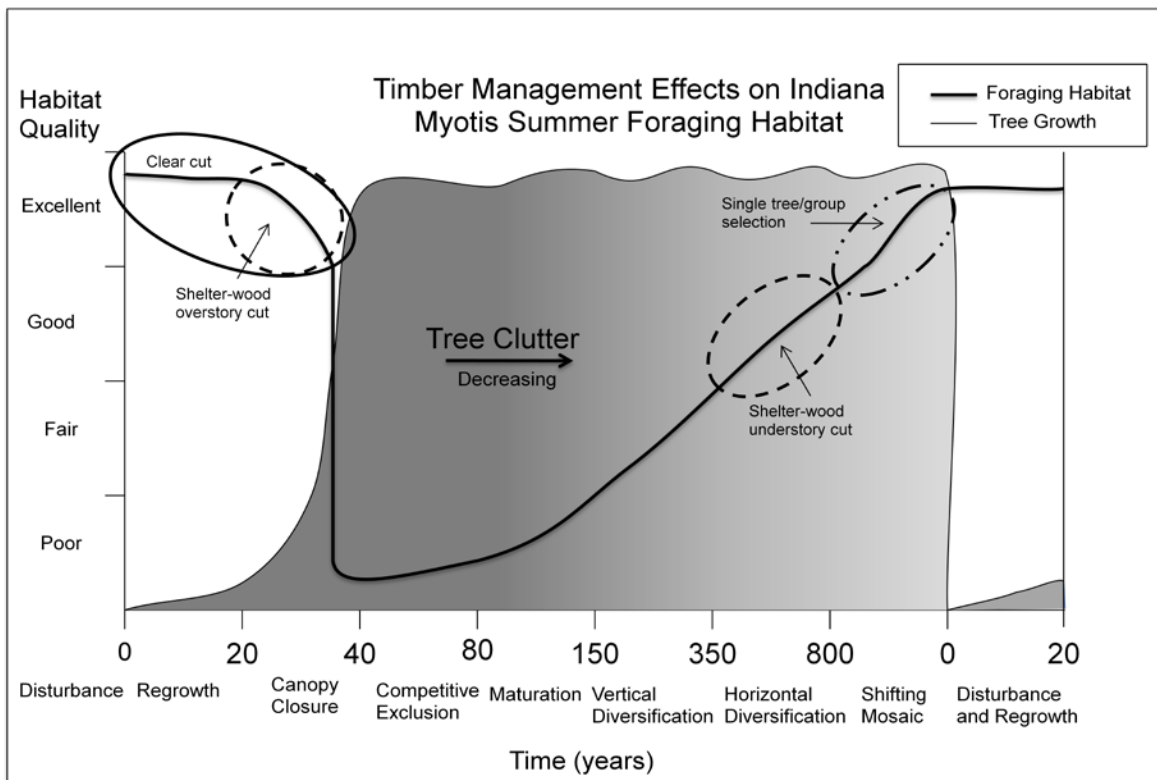


Figure 2. Indiana bat summer foraging habitat quality through forest successional time. Timber harvests are represented by circles that mimic forest successional time periods.

The affect of timber management practices on the quality of Indiana myotis summer roosting habitat through time is depicted in Figure 3. Clear cuts, shelter-wood cuts, and single tree/group selection all impact Indiana myotis summer roosting, i.e. tree snags, differently. Clear cuts, where all trees are cut down regardless of age and size, will destroy most snags and result in

poor habitat. Snags of significant sizes might not be available for many years, but snags will be more abundant as succession proceeds. However, snags can be retained during a clear cut and they will provide roosting habitat for some subsequent period. Shelter-wood cuts provide roosting habitat when unwanted tree species are girdled until the overstory is cut. Harvest can also damage trees and create roosts. Most snags created in the first shelter-wood cut may be knocked down or destroyed by either the overstory harvest or weather. Once the overstory is cut the habitat quality will be equivalent to a clear cut that has succeeded to young samplings and will continue to succeed naturally. Single tree/group selection cuts may destroy a few snags but leave most of the forest intact mimicking the shifting mosaic successional stage. TSI and prescribed fire will increase tree snags at any stage in forest succession.

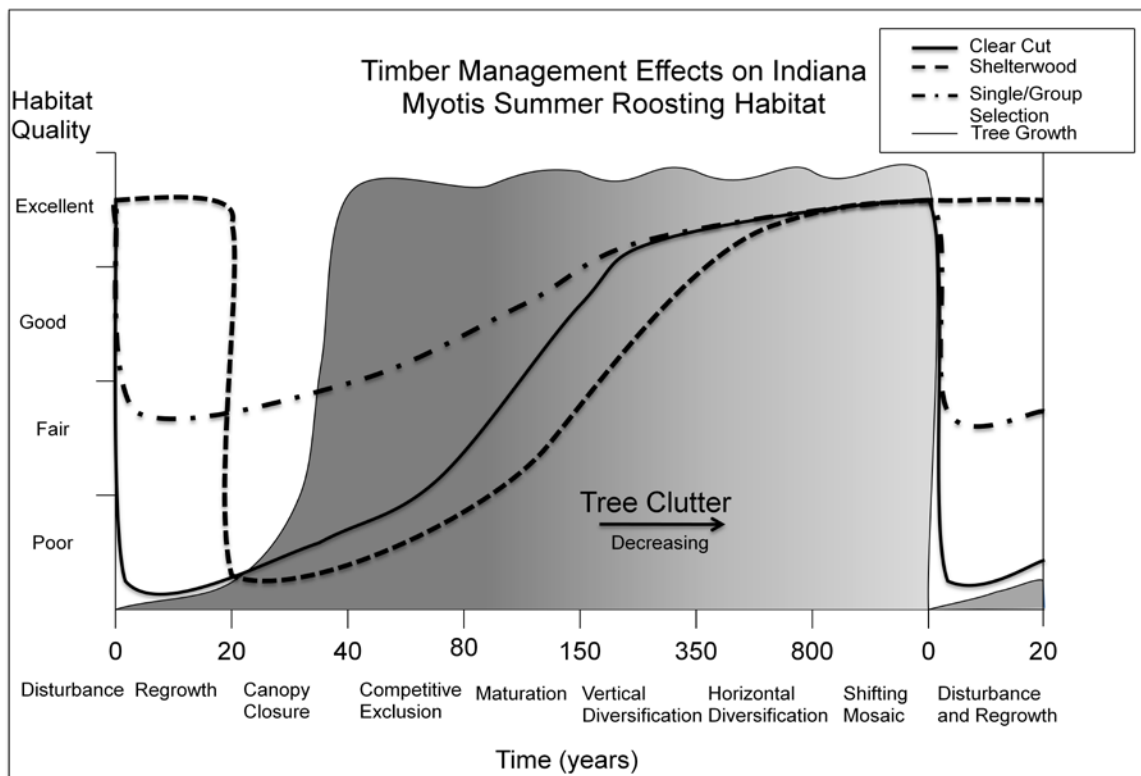


Figure 3. Indiana bat summer roosting habitat quality through forest successional time with different timber harvest techniques.

### Gray Myotis (*Myotis grisescens*)

The gray myotis (*Myotis grisescens*) is federally endangered and roosts in caves in both summer and winter. This does not exclude them from effects of timber management because caves often are located in forested areas, and the gray myotis forages over larger bodies of water and in wooded habitats (Brack and LaVal 2006; LaVal et al 1977, LaVal and LaVal 1980, Tuttle 1976a).

#### *Management*

Forests benefit the gray bat by providing foraging habitat and by protecting aquatic habitats that produce insect prey from siltation and excessive solar exposure and heating. Wooded travel corridors provide access to foraging areas. Retention of uncluttered forest stands near standing water or riparian zones will benefit this bat species.

### Eastern Red Bat (*Lasiurus borealis*)

The eastern red bat (*Lasiurus borealis*) roosts in foliage, boles of trees, grass or leaf litter, and under shingles in houses (Mager and Nelson 2001), but predominately roost in larger trees than occur randomly over the landscape (Menzel et al. 2000). Red bats forage in wooded areas including woodlots, areas of shrubby and sapling regeneration, and over pastures, open water, and parks (Hutchinson and Lacki 1999, Walters et al. 2006). The long thin wings of red bats suggests adaptation for foraging in relatively open habitats where foraging is more efficient foraging than in a cluttered environment (Elmore et al. 2004, 2005).

#### *Management*

Red bats may lose roosting habitat when timber is harvested, but in areas dominated by forest the impact may be small. Prescribed fires kill trees, possibility reducing roost availability.

In winter, prescribed fires may kill bats that roost in understory trees or leaf litter (Boyles and Aubrey 2005) unless conducted in fall and spring when temperatures are above freezing.

Forest management that incorporates open areas will provide foraging habitat; clear cuts and large group selection cuts create canopy openings. Prescribed burns, herbicide treatment, and other understory management reduce clutter. Logging corridors provides travel routes.

#### Northern Myotis (*Myotis septentrionalis*)

The Northern myotis (*Myotis septentrionalis*) usually lives in small groups in tree cavities or under bark (Sasse and Pekins 1996, Foster and Kurta 1999, Cryan et al. 2001, Lacki and Schwierjohann 2001, Menzel et al. 2002b, Carter and Feldhamer 2005). Northern myotis readily inhabit artificial roosts such as bat boxes (Whitaker et al. 2006). Like the Indiana myotis, the northern myotis, switches roosts often (Sasse and Pekins 1996, Foster and Kurta 1999, Cryan et al. 2001, Lacki and Schwierjohann 2001, Menzel et al. 2002b, Carter and Feldhamer 2005). The species may be a moth specialist and sometimes gleans prey such as spiders from plants (Brack and Whitaker 2001). The species apparently tolerates stand clutter and forages within forest stands (Putriquin and Barclay 2003) on forested hillsides or ridges (Owen et al. 2003). These bats also use scattered woodlots in an otherwise open habitat (Brack and Whitaker 2001, Brack et al. 2004, Owen et al. 2003).

#### *Management*

Northern myotis benefit from the creation of tree hollows and exfoliating bark (Sasse et al. 1996, Lacki and Schwierjohann 2001). Forests with a cluttered subcanopy may provide roosting and foraging habitat infrequently used by other bats. Although the northern myotis is cluttered adapted, forest stands that are “solid walls” of vegetation provide little usable habitat; however, single and group tree selection can create a suitable matrix of habitats composed of

different tree age classes over time. The northern myotis is common in Morgan-Monroe and Yellowwood State forests in central Indiana where single and group tree selection dominated timber management for 30 years (Sheldon 2007).

#### Big Brown Bat (*Eptesicus fuscus*)

The big brown bat (*Eptesicus fuscus*) is wide ranging and often encountered by the lay public. Big brown bats are colonial and roost in hollow trees, buildings, and other structures (Whitaker and Gummer 1992, Whitaker and Hamilton 1998, Cryan et al. 2001, Willis and Brigham 2004). Big brown bats forage in early-successional and open habitats and are relatively intolerant of clutter (Loeb and O'Keefe 2006). Specifically, big brown bats also forage in agricultural fields, small uncluttered wood lots, and urban habitats (Duchamp et al. 2004).

#### *Management*

This species often relies heavily on anthropogenic structures for roosts (Cope et al. 1991, Whitaker and Gummer 1992, Whitaker 1997, Duchamp et al. 2004) and artificial roosts. Retention of hollow trees will provide natural roosts for this species within forests.

Opening the forest canopy in large forest tracts will create foraging habitat. Early successional tree stands resulting from group selection and clear cuts will provide clutter free foraging habitat for a few years but through time the above habitats will become too cluttered for foraging.

#### Little Brown Myotis (*Myotis lucifugus*)

The little brown myotis (*Myotis lucifugus*) often roosts in large colonies in buildings (Whitaker and Hamilton 1998), but in some parts of the range it often roosts in trees (Crampton and Barclay 1998). In Pennsylvania, the little brown myotis was caught disproportionately often in riparian habitat and is more common along streams and near bodies of water (Brack 2009).

Little brown myotis may prefer wetter habitats and frequently forages over water (Barclay and Brigham 1991), often feeding on aquatic insects (Brack and Whitaker 2004). One study (Putriquin and Barclay 2003) suggested this species frequently uses edges of clear cuts but another encountered it in the center of clear cuts (Hogburg et al. 2002), suggesting they use all of the canopy openings. Wing morphology (Arita and Fenton 1997) and characteristics of echolocation calls (Broders et al. 2004) indicate adaptation to less cluttered environments than the Indiana and northern myotis.

### *Management*

Little brown myotis may respond similarly to the big brown bat to management with artificial roost structures. However, because it also roosts in tree cavities (Crampton and Barclay 1998) and under exfoliating bark (Whitaker et al. 2007) it may benefit from management that produces such roosts, like the Indiana and northern myotis. Because they routinely forage over water (Barclay and Brigham 1991), they should benefit from strategically located wildlife ponds and access to aquatic habitats like reservoirs, wetlands, and streams. Clear cuts and large group selections will provide foraging habitat for little brown myotis but it may benefit the species more if connected by a water body or water corridor.

### Eastern Pipistrelle (*Perimyotis subflavus*)

The eastern pipistrelle (*Perimyotis subflavus*) is a small bat that roosts in clusters of dead leaves in the canopy (Veilleux et al. 2003) and in cavities (Yates and Muzika 2006). Considered a clutter-adapted species (Menzel et al. 2005b), this bat forages in early-successional stands (Loeb and O'Keefe 2006). However, in suburban Indianapolis, this species foraged in every available habitat (Helms et al. Unpublished), and roosted in larger blocks of forest.

### *Management*

The species benefits from a mosaic of foraging habitats (early-successional stands, mature forest stands, and agricultural land). Management that favors foraging habitat for the northern myotis should also favor the eastern pipistrelle.

### Hoary Bat (*Lasiurus cinereus*)

The hoary bat (*Lasiurus cinereus*) roosts in tree canopies, often in stands of dominant mature trees (Perry and Thill 2007). In central Indiana, Sparks et al. (2005b) tracked a juvenile hoary bat to three roost trees (all large cottonwoods). Hoary bats may forage in open areas, consistent with their size, wing morphology, and echolocation call configuration (Barclay et al. 1999). At the Indianapolis airport, a juvenile hoary bat foraged predominately over open habits including agricultural areas and old fields during 4 nights (Sparks et al. 2005b).

### *Management*

The hoary bats may benefit from management similar to that employed for the eastern red bat, although it should include the retention of tall live trees for roosts. Clear cuts and open areas should provide foraging habitat, although the species likely often forages high above forested areas. Water sources adjacent to woodlands with an open canopy should benefit hoary bats. Because hoary bats can forage several miles from their roosts (Barclay et al. 1999), managed forests can provide roosting areas that allow the species to forage in open lands within and near the forests.

### Silver-haired Bat (*Lasionycteris noctivagans*)

The silver-haired bat (*Lasionycteris noctivagans*) is a migrant through the central Midwest and may only be affected by forest management during spring and fall. Silver-haired bats hibernate in a wide variety of habitats, occasionally including caves (Beer 1956), buildings



(Bartsch 1956), and even rock crevices (Barbour and Davis 1969). During summer, this species roosts in tree hollows (Betts 1998, Crampton and Barclay 1998) and presumably uses similar roosts during migration, although a much wider diversity of roosts may be used at this time (Barbour and Davis, 1969, Kunz 1982, Brack and Carter 1985). Hogburg et al. (2002) only found silver-haired bats foraging in the interior of clear cuts. However, they also feed extensively on caddisflies (Order Trichoptera), which live in streams and wetlands (Whitaker 1972, Whitaker et al. 1981a, b).

### *Management*

Retention of snags or live hollow trees may provide roosting opportunities during migration. However, during migration, this species, and many others, regularly increase the variety of roosts used (Hayward 1970); cracks and crevices in bark may be frequently used (Barclay et al. 1988), and thus trees such as shagbark hickory (Whitaker et al. 2004) may be of value. Clear cuts, streams, and other forest openings provide foraging habitat.

### Evening Bat (*Nycticeius humeralis*)

The evening bat (*Nycticeius humeralis*) uses tree cavities or buildings for maternity roosts (Watkins 1972, Whitaker and Gummer 2003). Foraging and roosting habitats may be shared with big brown bats (Duchamp et al. 2004). Evening bats may rely on wooded sites more than big browns, but also selectively forage in agricultural areas (Duchamp et al 2004). This species is detected 3three times more often above the forest canopy than below (Menzel et al. 2005b) making it hard to determine its abundance in forests.

### *Management*

Management may be similar to that for the Indiana bat, both for roosting and foraging, although the evening bat is more likely to roost in buildings. In addition, this species requires

foraging areas in close proximity to its roosts (Duchamp et al. 2004). Evening bats may not occupy upland forested areas (Whitaker et al. 2007); no evening bats were found during survey of two Indiana State forests that occupy dry upland ridges (Sheets et al. In Review).

Management plans should take this propensity into account.

#### Rafinesque's Big-eared Bat (*Corynorhinus rafinesquii*)

Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) roosts in very large hollow trees, caves, or anthropogenic structures in wooded areas (Clark 1991, Gooding and Langford 2004). Bridges in forested areas are also commonly used as both day and night roosts (MacGregor and Kiser 1998). Foraging habitats vary among regions: pine wood flats in Florida (Brown and Brown 1993), bottomland hardwoods in the Carolinas (Clark 1991), and oak-hickory stands in Kentucky (Hurst and Lacki 1999).

#### *Management*

Large uninterrupted tracts of forest provide this species the foraging habitat it needs. Retention or production of snags or living hollow trees (e.g. large sycamore trees) provides roosting habitat.

#### Townsend's Big-eared Bat (*Corynorhinus townsendii*)

Townsend's big-eared bat (*Corynorhinus townsendii*) occupies a broader range in the western US than in the eastern US, and in the Midwest it is relegated to an isolated and endangered subspecies, the Ozark big-eared bat (*Corynorhinus townsendii ingens*), which historically occurred in Missouri, but is now primarily found in Arkansas. The species primarily occupies caves although anthropogenic roosts are also used (Kunz and Martin 1982). In the eastern United States, anthropogenic structures are typically only used between nocturnal feeding bouts (Kunz and Martin 1982). Townsend's big-eared bat forages in riparian habitats and forest

edge (Fellers and Pierson 2002) in the west. Eastern populations feed over a variety of habitats including grassy fields (Burford and Lacki 1995), edges of streams (Clark et al. 1993), along the edges of forests (Wethington et al. 1996), and over agricultural crops (Brack pers comm.).

### *Management*

If not extirpated from Missouri, the species might benefit from forest management options discussed for Rafinesque's big-eared bat with more canopy openings and less clutter.

### Eastern Small-Footed Myotis (*Myotis leibii*)

The eastern small-footed myotis occupies mountainous regions mostly in the eastern U.S., (Whitaker and Hamilton 1998). Little information is known on summer roosts of eastern small-footed myotis some have been found in barns (Tuttle and Heaney 1974) and may use caves and cracks in hillsides (Whitaker and Hamilton 1998). Foraging ecology of this bat is still little understood, but most likely forages in forested areas. Moorsman et al. (2007) suggest that the diet of the small-footed myotis is similar to the northern myotis and little brown myotis, and may forage in similar habitats.

### *Management*

The lack of information on foraging and roosting habits of the eastern small-footed myotis and its rarity in the Midwest makes it nearly impossible to suggest management techniques. However, protections of forested areas adjacent to preferred roosting habitat, cliff faces, would be a priority. Forests with reduced clutter will benefit the eastern small-footed myotis by providing foraging habitat; travel corridors will also benefit the species.

### Southeastern myotis (*Myotis austroriparius*)

Southeastern myotis is a species of special concern in the Midwest and throughout its range. The southeastern myotis is found rarely in southern Illinois and in the past in Indiana; it is more common in the southern U.S. This species uses hollow trees as maternity roosts in Southern Illinois and is known to use anthropogenic structures and caves throughout its range (Whitaker and Hamilton 1998). In Southern Indiana, this species has only been found hibernating in caves and is likely extirpated from the state (Whitaker et al. 2007).

### *Management*

There is little natural history information on southeastern myotis in the Midwest. Determining how timber harvest may affect this species proves difficult. Southeastern and little brown myotis may share similar foraging habitats; Zinn and Humphrey (1981) report that southeastern myotis feed over water ways. Roosting in hollow trees and using the same foraging habitat may suggest the southeastern myotis will benefit from management similar to that described for the little brown myotis.

CHAPTER 2  
BATS OF YELLOWWOOD AND MORGAN-MONROE STATE FORESTS BEFORE  
TIMBER HARVEST

This study is part of the Hardwood Ecosystem Experiment, a multi-agency, multi-university effort to study effects of forest management practices on a variety of wildlife, including bats, on the Yellowwood and Morgan-Monroe state forests in Indiana. Before experimental harvest of the forests, bats were sampled using mist nets at four locations in Morgan-Monroe and five locations in Yellowwood State Forests twice during each summer 2006-2008. Netting locations were adjacent to forest stands scheduled for experimental manipulations following conclusion of netting in 2008. This effort produced 342 bats (in order of abundance): northern myotis (*Myotis septentrionalis*), eastern red bat (*Lasiurus borealis*), big brown bat (*Eptesicus fuscus*), Indiana bat (*Myotis sodalis*), little brown bat (*Myotis lucifugus*), eastern pipistrelle (*Perimyotis subflavus*), hoary bat (*Lasiurus cinereus*), and silver-haired bat (*Lasionycteris noctivagans*). These data are supplemented with those from a survey at Morgan-Monroe and Yellowwood state forests during 2004 that yielded 222 bats and supplemental netting in 2006-2008 that added 16 bats. These data provide a baseline to understand how bats are affected by long-term forest manipulations initiated in summer 2008.

## Introduction

Many bats rely on forested habitats for foraging and roosting (Barclay and Brigham 1996, Barclay and Kurta 2007). Although bats are a critical element of forests, an understanding of how bats are affected by many forest management practices remains elusive (Lacki et al. 2007). Most research has addressed short-term responses of bats to common management techniques, such as thinning (Kurta and Kennedy 2002, Tibbels and Kurta 2003, Miller 2003, Fisher and Wilkinson 2005), prescribed burning (Boyles and Aubrey 2005, Boyles et al. 2005, Carter et al. 2000), and clear cuttings (Hogburg et al. 2002, Putriquin and Barclay 2003, Owen et al. 2004). However, effects of other commonly used techniques on bats, especially single tree and group selection, remain unknown, despite the fact that in Morgan-Monroe and Yellowwood state forests this has been the management paradigm. Further, little is known about long-term effects of management practices on bats. Finally, past research involving bats typically considered only one management activity at a time, even when conducted within forest ecosystems receiving manipulations across multiple temporal and spatial scales. To better understand impacts of forest management techniques, the Indiana Department of Natural Resources (IDNR), Division of Forestry (DOF) designed a series of forest manipulations to examine the effects on bats, within the context of the Hardwood Ecosystem Experiment (HEE, Appendix A), which plans to continue the experiment for 100 years at Morgan-Monroe and Yellowwood state forests. Provided herein is an overview of the bat community before timber harvest, and hypotheses on how each species will respond to these manipulations.

## Methods and Materials

*Study Area*

Morgan-Monroe and Yellowwood state forests are in Morgan, Monroe, and Brown counties in south-central Indiana (Figure 2). The forests are similar in composition (oak and hickory) and are managed as one unit by DOF. Both consist mainly of high ridges with steep runoff streams and upland forests. Yellowwood has 9,459 ha and Morgan-Monroe >9,720 ha of forest subject to harvest. Both forests were established by Indiana legislation during the 1920s and 1930s after they proved unsuitable for agriculture (Sheldon 2007).

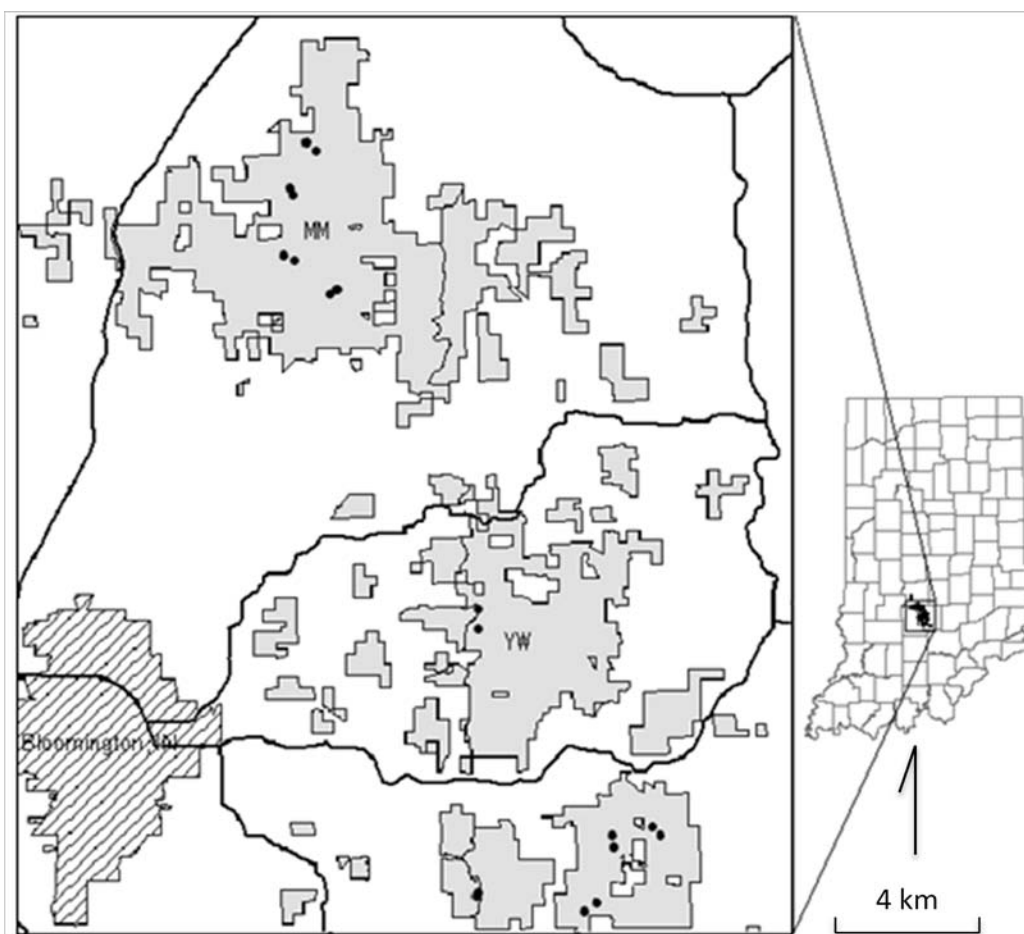


Figure 4. Location of Morgan-Monroe (MM) and Yellowwood (YW) state forests (gray areas) in relation to Bloomington, Indiana (hash mark). Solid circles denote net sites.

### *Bat Sampling*

Bats were captured using four multi-tiered mist net sets (Avinet, Inc. Dryden, New York) placed at two sites in each of the nine SUs. Sites were netted twice per summer (May 15 to August 15) during years of 2006, 2007, and 2008 on nonconsecutive nights, resulting in 144 net nights of sampling each year with total of 432 net nights. At each site mist nets sets were arranged to maximize bat captures with most placed across logging roads. Habitat descriptions, including tree species, potential roost trees, undergrowth species, and distance to water sources were recorded. Weather conditions were monitored including temperature (Celsius), estimated cloud cover, and wind speed. Mist nets were set by nightfall and left in place for 5 hours. Nets were monitored constantly and checked at least every 10 minutes. Data collected on captured bats included species, sex, reproductive condition, right forearm length, weight, and an estimate of age (juvenile or adult). Numbered metal bands (Prozana Ltd, Icklesham, East Sussex, United Kingdom) were fitted to the right (males) or left (females) forearm to allow identification of individual bats. Statistical analyses were conducted with SPSS 11.0 for Windows with a rejection level of  $\alpha = 0.05$  used throughout. A Kruskal-Wallis one-way analysis of variance test for non-parametric data was used to compare the capture rates of each species among years and MacArthur's (1972) diversity index across all years.

In addition to this standardized netting, I will also report data from two supplemental data sets. First, during 2004 bats were surveyed with mist nets in Morgan-Monroe and Yellowwood state forests as part of an effort to locate colonies of the federally endangered Indiana bat (*Myotis sodalis*) while developing a Habitat Conservation Plan for this species on DOF properties. Second, 24 net nights during 2006-2008 did not meet pre-specified weather conditions of rain or



temperature. Bats captured on those nights were not included in the analysis of standardized data and the site was netted again. Both data sets are included to provide a more complete survey.

### Results

In 2006, 140 bats representing 6 species were captured, 67 Morgan-Monroe State Forest and 73 in Yellowwood State Forest, including 53 northern myotis (*Myotis septentrionalis*), 46 eastern red bats (*Lasiurus borealis*), 27 big brown bats (*Eptesicus fuscus*), 5 little brown myotis (*Myotis lucifugus*), 5 Indiana myotis, and 4 eastern pipistrelles (*Perimyotis subflavus*) (Table 2). The MacArthur (1972) diversity index for Morgan-Monroe and Yellowwood forests was 2.7 and 3.5, respectively, and 3.5 combined.

In 2007, 87 bats representing 7 species were captured, 47 Morgan-Monroe State Forest and 40 in Yellowwood State Forest (Table 2), including 37 northern myotis, 26 eastern red bats, 12 big brown bats, 4 little brown myotis, 3 Indiana myotis, 3 eastern pipistrelles, and 2 hoary bats (*Lasiurus cinereus*). The MacArthur (1972) diversity index for Morgan-Monroe and Yellowwood forests was 2.4 and 4.0, respectively, and 3.0 combined.

In 2008, 115 bats were captured, 46 in Morgan-Monroe State Forest and 69 in Yellowwood State Forest, including 41 northern myotis, 32 eastern red bats, 21 big brown bats, 2 little brown myotis, 8 Indiana myotis, 10 eastern pipistrelles, and 1 silver-haired bat (*Lasionycteris noctivagans*). The MacArthur (1972) diversity index for Morgan-Monroe and Yellowwood forests was 4.6 and 4.5, respectively, and 4.0 combined. Capture rates for each species were similar across the 3 years ( $p = 0.091$ ) (Table 2).

In 2004, 222 bats representing 6 species were captured (Table 3), including 109 northern myotis, 76 eastern red bats, 21 big brown bats, 5 little brown myotis, 9 Indiana myotis, and 2

hoary bats (Brack and Hawkins In Litt). The MacArthur (1972) diversity index for Morgan-Monroe and Yellowwood forests was 2.7 individually and combined. Supplemental netting in 2007 (5 bats) and 2008 (11 bats) yielded 5 big brown bats, 6 eastern red bats, 4 northern myotis, and 1 silver-haired bat (Table 3).

Table 2. Numbers of bats captured while mist netting in 2006, 2007, and 2008 (each with 144 net nights), within Morgan-Monroe and Yellowwood state forests, Indiana. Kruskal-Wallis test comparing capture rates of species among years, 2006-2008.

Species	2006		2007		2008		Total		Kruskal-Wallis	
	#	#/net-night	#	#/net-night	#	#/net-night	#	#/net-night	$\chi^2$	P
<i>M. septentrionalis</i>	53	0.37	37	0.26	41	0.28	131	0.30	0.853	0.653
<i>L. borealis</i>	46	0.32	26	0.18	32	0.22	104	0.24	5.293	0.071
<i>E. fuscus</i>	27	0.19	12	0.08	21	0.15	60	0.14	3.590	0.166
<i>M. sodalis</i>	5	0.03	3	0.02	8	0.06	16	0.04	0.303	0.859
<i>P. subflavus</i>	4	0.03	3	0.02	10	0.07	17	0.04	0.889	0.641
<i>M. lucifugus</i>	5	0.03	4	0.03	2	0.01	11	0.03	1.121	0.571
<i>L. cinereus</i>	0	0.00	2	0.01	0	0.00	2	0.00	4.077	0.130
<i>L. noctivagans</i>	0	0.00	0	0.00	1	0.01	1	0.00	2.000	0.368
<b>Total</b>	140	0.97	87	0.60	115	0.80	342	0.79	4.784	0.091

Table 3. Supplemental mist netting data for 2004 (101 net nights) (Brack and Hawkins, In Litt.), 2007 (8 net-nights), and 2008 (16 net-nights) at Morgan-Monroe and Yellowwood state forests, Indiana.

Species	2004		2007		2008	
	#	#/net-night	#	#/net-night	#	#/net-night
<i>M. septentrionalis</i>	109	1.08	2	0.25	2	0.13
<i>L. borealis</i>	76	0.75	3	0.38	3	0.19
<i>E. fuscus</i>	21	0.21	0	0.00	5	0.31
<i>M. sodalis</i>	9	0.09	0	0.00	0	0.00
<i>P. subflavus</i>	5	0.05	0	0.00	0	0.00
<i>M. lucifugus</i>	2	0.02	0	0.00	0	0.00
<i>L. cinereus</i>	0	0.00	0	0.00	0	0.00
<i>L. noctivagans</i>	0	0.00	0	0.00	1	0.06
<b>Total</b>	222	2.20	5	0.63	11	0.69

## Discussion

The eight species of bats currently found in these two state forests are typical of the region's forested areas (Whitaker and Hamilton 1998, Mumford and Whitaker 1982). A ninth species, the evening bat (*Nycticeius humeralis*) also may inhabit these forests, but is most often caught in lowland areas (Whitaker et al. 2007), which were not well represented in the sample.

Bat species numbers reflect the structure of Morgan-Monroe and Yellowwood state forests. A cluttered adapted species, northern myotis, was most commonly caught in both forests. Single tree and group selection (the timber management paradigm for both forests) mimics forest structure that the northern myotis prefers (Putriquin and Barclay 2003). Eastern red and big brown bats were also common, but most net sites were in uncluttered corridors, where red and big brown bats travel and forage. The eastern pipistrelle was caught infrequently, which dissimilar to other studies in similar forests in southern Indiana were they are common

(Brack et al. 2004, Brack and Whitaker 2004). The Indiana bat was caught infrequently, suggestive of its endangered status. Little browns myotis prefer to forage over water (Anthony and Kunz 1977, Brack In Press) which was rare in the upland forest. Hoary bats are rarely caught in mist nets, possibly because they are commonly active above the area sampled with mist nets. Silver-haired bats are usually caught in early spring during migration and not expected in large numbers.

Our expectation is that all eight species will be present following timber harvest, but that the community composition may change as each species responds to changes in habitat. Short term, bats may be killed if they are roosting in a tree when it is harvested (Humphrey et al. 1977, Belwood 2002). However, succession from young dense forests to more open mature forest will benefit most species, especially the Indiana bats. Below we summarize the foraging and roosting needs of the eight species in Morgan-Monroe and Yellowwood forests, and based on these habitat needs, make predictions about how each species will respond to the various planned timber harvests in both the short-term (i.e. immediately after harvest) and long-term.

Indiana bats typically roost under tree bark (Humphrey et al. 1977) and forage at the air-vegetation interface (Sparks et al. 2005a), including along logging roads, riparian streams, above and below the canopy, and at the edge of clearings. Foraging Indiana bats may make increased use of edge habitat created by clear cuts and the more open forests created by other timber harvest techniques (Menzel et al 2001). Further, regenerating clear cuts will closely resemble seedling plantations at the Indianapolis Airport where Indiana bats forage; (Sparks et al. 2005a); if dominated by oak species (as planned), clear cuts may provide a source of Asiatic oak weevils (*Cyrtopistomus castaneus*) which are both an important consumer of young oaks and acorns and a common food item of several bat species including the Indiana bat (Brack 1983, Brack and

LaVal 1985; Tuttle et al. 2006). However, it is also likely that in 30-80 year old timber stands will be too cluttered for Indiana bats.

It is likely that some Indiana bat roost trees will be lost to harvest. However, given the relatively small size of clear cuts ( $\leq 10$  acres), the presence of suitable roost trees in unharvested blocks, buffer areas, and retention of snags in harvested areas, should provide much suitable roosting habitat will remain. Outside clear cuts, falling trees and logging equipment will damage some trees, which may help create suitable roosts for this species (Gumbert et al. 2002). Areas that successfully yield mature oak-hickory forests may benefit this species as it frequently roosts in shagbark (*Carya ovata*) and shellbark (*C. lacinosa*) hickories and oaks (Callahan et al. 1997, Kurta 2005, Whitaker and Sparks 2008) during summer. Long-term, the senescence and death of oaks and hickories during succession may provide valuable roost sites.

Northern myotis typically roost in tree cavities or under bark (Lacki and Schwierjohann. 2001) and forage in forest interiors (Brack and Whitaker 2001; Owen et al. 2003, Putriquin and Barclay 2003). Northern myotis are interior forest species (Owen et al. 2003, Putriquin and Barclay 2003), so these bats are less likely to use clear cut areas than other species. For example northern myotis were captured less frequently following clearing of a large forest patch along Prairie Creek in Vigo County, Indiana (Sparks et al. 1998). Other types of timber harvest are unlikely to seriously impact this species as long as the preferred roosts (hollow trees) remain common in the surrounding landscape, and the harvest protocol calls for the retention of snags. The species may be among the most tolerant of cluttered forests (dense subcanopy) (Owen et al. 2003), and thus as forest management practices create less cluttered forest it may face competition with other species for foraging and roosting habitat.

In Indiana, most documented summer roosts of little brown myotis have been in anthropogenic structures, especially attics of buildings and expansion cracks of bridges, although they occasionally roost under the exfoliating bark of dead trees (Whitaker et al. 2007). Little brown myotis forage along forest edges (Putriquin and Barclay 2003), in centers of clear cuts (Hogburg et al. 2002), and over aquatic habitats (Anthony and Kunz 1977, Brack In Press). As such, these bats are likely to benefit from small clear cuts and shelter-woods and not single or group selection harvests. As clear cuts and shelter-woods age, they are likely to become too cluttered for this species to use extensively.

Big brown bats use anthropogenic structures for roosting during both summer and winter (Whitaker et al. 2007), although some individuals roost in tree cavities after maternity colonies break up in late summer (Duchamp et al. 2004, Whitaker 1996). Big brown bats forage in early successional and open forested habitats (Loeb and O'Keefe 2006) and a wide variety of other non-forested habitats (Duchamp et al. 2004). It is suspected that openings created by clear cuts and shelter-woods will provide increased foraging opportunities for big brown bats.

Eastern red bats roost primarily in tree foliage (Mager and Nelson 2001), and forage in open habitats (Hutchinson and Lacki 1999, Walters et al. 2006). Clear cuts will remove potential roost trees but create open foraging habitat in a cluttered landscape (Elmore et al. 2004). It is suspected that the overall availability of roost trees in the surrounding uncut blocks will provide a ready supply of suitable roost trees for roosting. As such, the greatest impact on red bats may be the increase in open lands where they can forage.

Eastern pipistrelles roost in leaf clusters in trees (Veilleux et al. 2003), tree cavities (Yates and Muzika 2006), and anthropogenic structures (Whitaker 1998). Pipistrelles foraged in forest openings and early successional areas in South Carolina (Loeb and O'Keefe 2006) and in

cluttered forests (Menzel et al. 2005b), but at the Indianapolis Airport, closer to our project area, this species uses a variety of land classes such as open fields, above saplings, and forest (Helms et al. Unpublished). As such, eastern pipistrelles may be a habitat generalist and will forage in habitats in different successional stages.

Hoary bats roost mainly in tree canopies (Perry and Thill 2007, Sparks et al 2005b) and based on wing size and call frequency, forage in open areas (Barclay et al. 1999, Elmore et al. 2004). Hoary bats may forage in new clear-cut and shelter-wood harvest areas. Currently hoary bats are rarely encountered (we captured 2 during this study), but we suspect that the species roosts in these forests and forages in surrounding un-forested areas and above the canopy (Sparks et al. 2005b). Roosting habitat will remain abundant in the surrounding areas that will not be harvested.

Silver-haired bats summer in upper states of the Midwest and Canada where they roost in tree hollows (Parsons et al. 1986, Whitaker and Hamilton 1998) and forage in centers of clear cuts (Hogburg et al 2002). Silver-haired bats migrate through central Indiana during spring and autumn (Novakowski 1956, Munford and Whitaker 1982), although some hibernate in southern Indiana (Whitaker et al. 2007). As such, it is unlikely that timber harvests in Indiana will impact this species in a meaningful way if suitable roosts remain on the landscape.

As the HEE moves forward, the data presented herein will provide a valuable reference point to determine how the bat community responds to forest management techniques. With new openings created by timber harvest every 20 years, a mosaic of clear-cuts in varying successional states, uneven-aged stands, and controls (which eventually will succeed to shifting mosaic, beech maple stands) will provide species of bats with foraging habitats throughout this 100 year project. Eventually, comparison of the bat community within these habitat types before and after

timber harvests should provide substantial insight into ways to manage bats and timber production on the same land and will provide base line data when White Nose Syndrome (WNS) arrives in the Midwest likely killing large numbers of bats.



CHAPTER 3  
HABITAT OCCUPANCY BY BATS IN TWO INDIANA FORESTS PRIOR TO TIMBER  
HARVEST

To study timber management effects on habitat occupancy by different bats species in two state forests in Indiana, I placed Anabat II bat detectors in four habitat types: interior forest, canopy gap, forest edge, and corridor. In summer 2007, I obtained calls from 7 species: eastern red bat (*Lasiurus borealis*), eastern pipistrelle (*Perimyotis subflavus*), big brown bat (*Eptesicus fuscus*), northern myotis (*Myotis septentrionalis*), Indiana myotis (*Myotis sodalis*), little brown myotis (*Myotis lucifugus*), and hoary bat (*Lasiurus cinereus*). During 337 sample nights 3113 calls (842 corridor, 681 edge, 1075 canopy gap, and 515 interior) were obtained. I modeled habitat occupancy after correcting for bats that were not detected. Northern myotis used all habitats equally. All other species occupied canopy gaps the most followed by forest edge, corridors, and forest interior. This study provides an opportunity to predict likely impacts of management activities on the bat community, and indicates that nocturnal habitat will be improved for most species of bats.

Introduction

Differences in occupancy (use) of habitats by different bat species may be important predictors of the response of bats to various timber management practices (Yates and Muzika 2006). I predicted that species of bats would differ in their proportional occupancy of four types

of habitats that characterize Midwestern forests (interior forest, forest edge, forest canopy gaps, and corridors). To test this hypothesis, I sampled these habitats with bat (ultra sonic sound) detectors in Morgan-Monroe State Forest and Yellowwood State Forest in Indiana prior to a series of experimental timber harvests (Appendix A), where I previously captured eight species of bats during a mist netting survey (Sheets et al. In Review). Bat detectors have become an increasing important tool to study bats and can be used to sample large or multiple locations simultaneously. Permanent detecting stations can be used for long-term studies and to compare activity of bats among habitats (Brigham et al. 1997, Zimmerman and Glanz 2000, Owen et al. 2004). The experimental timber harvests in Morgan-Monroe and Yellowwood state forests is a long term study (100 years) that will create new canopy gaps, edge, and logging roads. From these data I hope to predict the response of bats to planned forest manipulations.

Bat species may use forest habitats differently; activity levels may vary across habitats for a variety of reasons (Hayes 1997) and their response to timber management may determine species occupancy in certain habitats. I predicted corridors would have the highest occupancy, followed by edge, canopy gaps, and interior forest. Corridors were predicted to have the highest occupancy because bats use them to commute among roosts and foraging areas. It was anticipated that edge habitat would have more occupancy throughout the night, because they are often used by foraging eastern pipistrelles (*Perimyotis subflavus*), Indiana myotis (*Myotis sodalis*), and little brown myotis (*Myotis lucifugus*) (Menzel et al 2001, Menzel et al. 2005a, Putriquin and Barclay 2003). Eastern red (*Lasiurus borealis*), big brown (*Eptesicus fuscus*), silver-haired (*Nycticeius humeralis*), eastern pipistrelle, and hoary bats (*Lasiurus cinereus*) was predicted to occupy canopy gaps more than other habitats. Canopy gaps may be avoided at dusk and dawn to avoid predation by diurnal birds of prey (Sparks et al. 2000), resulting in low

number of calls at these times. I predicted that forest interior would have the lowest occupancy. The northern myotis (*Myotis septentrionalis*) was predicted as most likely to occupy forest interiors (Putriquin and Barclay 2003, Owen et al. 2003).

## Methods and Materials

### *Study Area*

This study was conducted on Morgan-Monroe State Forest and Yellowwood State Forest in Morgan, Monroe, and Brown counties in south-central Indiana (Figure 3). Both forests (19,000 ha combined) were established in the 1920s after the high ridges, steep slopes, and narrow streams proved unsuitable for agriculture (Sheldon 2007). Today, these sites are covered in upland forests dominated by oaks (*Quercus* sp.) and hickories (*Carya* sp.), broken by occasional corridors (mostly logging roads) and previously harvested areas. Timber management consisted of single tree and group selection in both forests (Sheldon 2007). During the next 100 years, 9 management units within these forests will be subjected to a variety of timber management practices including even-aged (clear cuts and shelter-wood cuts) and uneven-aged (single-tree and group-tree selection) harvest, and control areas of no harvest areas (Appendix A).

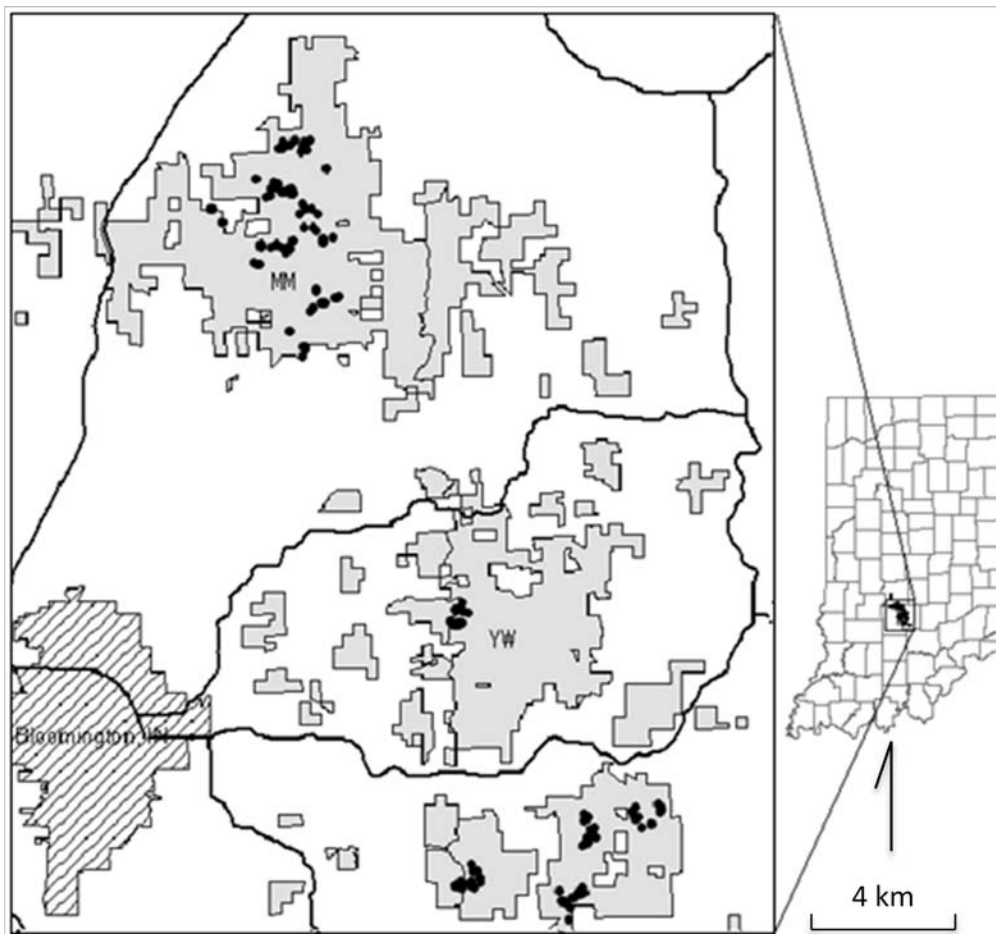


Figure 5. Location of Morgan-Monroe (MM) and Yellowwood (YW) state forests (gray areas) in relation to Bloomington, Indiana (hash mark). Solid circles denote detector sites.

### *Habitats*

I sampled 4 types of habitats (forest interior, forest edge, canopy gaps, and corridors) that are abundant and easily defined. Forest interior is a matrix of trees of different ages (i.e. forest). Forest edge habitat is the interface of the forest with open lands, largely agricultural fields. Canopy gaps are non-linear openings (<1 ha - 2 ha) in the forest canopy. Corridors are fire and hiking trails, logging and access roads, and utility corridors.

*Sampling of Bats*

Bat communities at each site were sampled acoustically in the summer of 2007 using Anabat II bat detectors and a digital recording device (Anabat II Zero Crossing Analysis Interface Modules, ZCAIMs, Titley Electronics, Ballina, New South Wales, Australia: Detectors hereafter). Each detector was set 1 m above ground on a polyvinyl chloride (PVC) pipe and housed in a plastic storage container with a 45° PVC elbow at one end. Within the storage container, microphones were placed 1 cm behind the PVC elbow (Duchamp et al. 2006), and detectors were aligned on an azimuth selected from a random numbers table. If detectors aligned with an obstacle or road that could impede recordings, another direction was selected. To improve accuracy of call identification, detectors were placed in areas relatively free of clutter, which increases detection and decrease intraspecific call variability. Inherent with the use of bat detectors are assumptions that the probability of detection is constant and is affected by abundance (Duchamp et al. 2006).

A total of 337 nights of sampling was conducted with 24 nights in forest edges, 36 in corridors, 48 in canopy gaps, and 229 in interior forests. Sample sites for forest edge and canopy gap habitats were picked by locating as many sites of each as possible and randomly selecting among these using a random numbers table. Corridor sites were chosen at established net sites on existing logging trails (Sheets et al. In Review). Additional corridor sites were chosen using the methods used for edges and canopy gaps. At forest interior sites, a single detector was placed at each of three locations (one outside, one at the edge, and one inside) of the proposed timber harvest sites (Appendix A). Each detector site was sampled twice for a single night each - once early (15 May-July 8) and once late (July 9-15 August) in the season (Duchamp et al. 2006).

*Statistical Analysis*

Calls were analyzed using program ANALOOK (version 1.6, Titley Electronics) and identified to species based on comparison with calls in reference libraries (Britzke 2000, Murray 2001, Britzke 2003). This comparison was completed using an artificial neural network. Bat calls were identified to species by looking at the proportion of calls identified as a species and setting a cut off of 0.6 (i.e. at least 60% of the calls in a sequence had to be identified as the same bat species) and more than three calls present in the sequence, using Identification (run in program R version 2.41, package MASS). We used identified calls to determine presence or absence of a species and the level of activity. Activity levels were measured as the number of minutes in which a call of each species was detected throughout the night (Miller 2001). Measuring calls per minute reduces bias from bats that circled near a detector (Miller 2001). Bat detection probability (potential of a bat being detected when present) at a given habitat, can influence perceived occupancy (Loeb and O'Keefe 2006, Yates and Muzika 2006). Occupancy is the probability of "use" estimated by how often a bat species was missed, by calculating how hard a species is to detect and compensates for low detection. Bat detection probabilities for species differences and habitat differences were estimated by occupancy models in program MARK for "high intensity use" (Gorresen et al 2008). Quantified intensity of use based on minutes of use was used instead of number of call pulses and with identified call sequences, ignoring feeding buzzes. We used these data to determine whether species were evenly proportioning their time among the 4 habitat types. Seven occupancy models were developed with Akaike's Information Criteria corrected for sample size (AICc), difference between models (Delta AICc), detection probability (p), portion of habitat used (Psi), and the number of parameters (npar) calculated.

## Results

Seven bat species were detected and a total of 4841 calls identified: 1473 eastern red bat, 1364 eastern pipistrelle, 928 big brown bat, 549 northern myotis, 409 Indiana myotis, 104 little brown myotis, and 14 hoary bat. After filtering to one call per minute, we obtained 3113 minutes of useable calls, including 842 in corridors, 681 along edges, 1075 in canopy gaps and 515 in interior forests. Out of 337 detector sampling nights, more bats were proportionally detected in edge, than corridors, followed by canopy gaps, and interior forest (Figure 6). Bats of all species were equally detectable in each habitat except for Indiana and northern myotis which were harder to detect in forest interior than in other habitats (Table 4). The model with the lowest AICc (best fit) considered each habitat and species separately (Table 5). Samples with high intensity use were those where the number of minutes was greater than the median number of minutes recorded for that species (4 minutes for *L. borealis*, 3 minutes for *E. fuscus*: and 2 minutes for all other species, Figure 7).

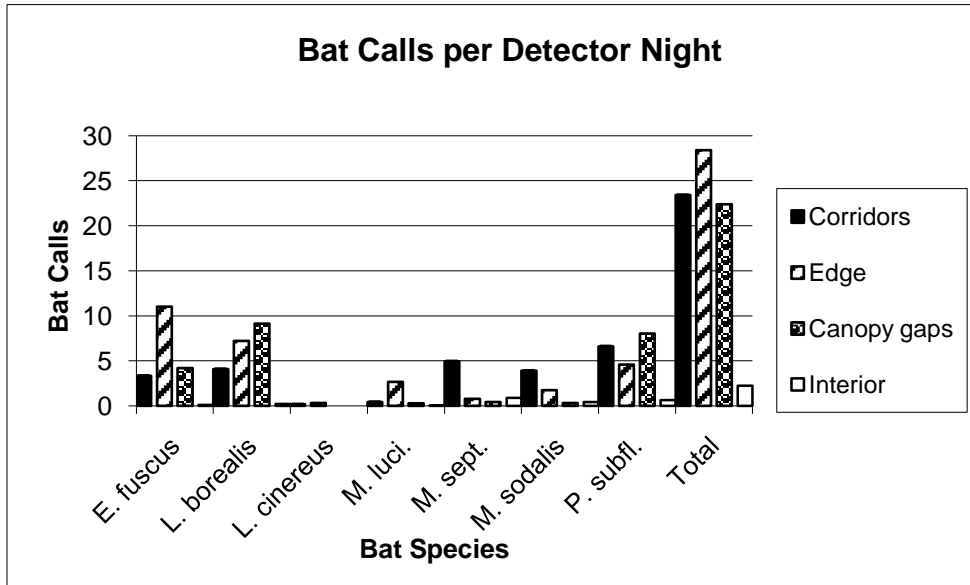


Figure 6. Bat species (counting one call per minute) for each species in each habitat per detector night, based on 337 bat detector sample nights: corridor (36), edge (24), canopy gap (48), and interior forest (229).

Table 4. Probability of detection for bat species in each habitat.

	<i>E. fuscus</i>	<i>L. borealis</i>	<i>M. lucifugus</i>	<i>M. sept.</i>	<i>M. sodalis</i>	<i>P. subflavus</i>
<b>Corridors</b>	0.9491 ±0.1608	0.8964 ±0.1294	0.3816 ±0.1336	0.4389 ±0.0828	0.3677 ±0.0853	0.7907 ±0.1714
<b>Forest Edges</b>	0.9631 ±0.1377	0.9156 ±0.1330	0.4216 ±0.1259	0.4812 ±0.0941	0.4070 ±0.0946	0.8227 ±0.1641
<b>Canopy Gaps</b>	0.8650 ±0.1194	0.8005 ±0.1252	0.2564 ±0.0797	0.3020 ±0.0644	0.2457 ±0.0624	0.6528 ±0.1277
<b>Forest Interiors</b>	0.6409 ±0.1773	0.5871 ±0.1564	0.1294 ±0.0503	0.1559 ±0.0250*	0.1233 ±0.0387*	0.4200 ±0.1164

\* significant difference ( $p < 0.05$ )



Table 5. Occupancy models:  $p$  = detection probability,  $\Psi$  = portion of habitat used,  $AICc$  = Akaike's Information Criteria,  $\Delta AICc$  = difference between model  $AICc$  and of the best model,  $npar$  = number of parameters in the model.

<b>Psi Description</b>	<b>Model</b>	<b>npar</b>	<b>AICc</b>	<b>Delta AICc</b>
Psi-separate habitat and species differences	$p(\sim\text{habitat} + \text{species})\Psi(\sim\text{habitat} + \text{species})$	18	923.7605	0.00000
Psi-separate habitat and EPLA	$p(\sim\text{habitat} + \text{species})\Psi(\sim\text{habitat} + \text{EPLA})$	14	928.2764	4.51593
Psi-separate habitat and Myotis Sp. differences	$p(\sim\text{habitat} + \text{species})\Psi(\sim\text{habitat} + \text{MYSP})$	14	930.2360	6.47552
Psi-separate interior habitat specific + species differences	$p(\sim\text{habitat} + \text{species})\Psi(\sim\text{interior} + \text{species})$	16	935.3456	11.58508
Psi-separate interior habitat and EPLA	$p(\sim\text{habitat} + \text{species})\Psi(\sim\text{interior} + \text{EPLA})$	12	935.8835	12.12299
Psi-separate habitat and PISU differences	$p(\sim\text{habitat} + \text{species})\Psi(\sim\text{habitat} + \text{PISU})$	14	939.2024	15.44188
Psi-separate habitat	$p(\sim\text{habitat} + \text{species})\Psi(\sim\text{habitat})$	13	942.9997	19.23917

EPLA = combined big brown and red bat differences, MYSP = northern myotis, and PISU = eastern pipistrelle.

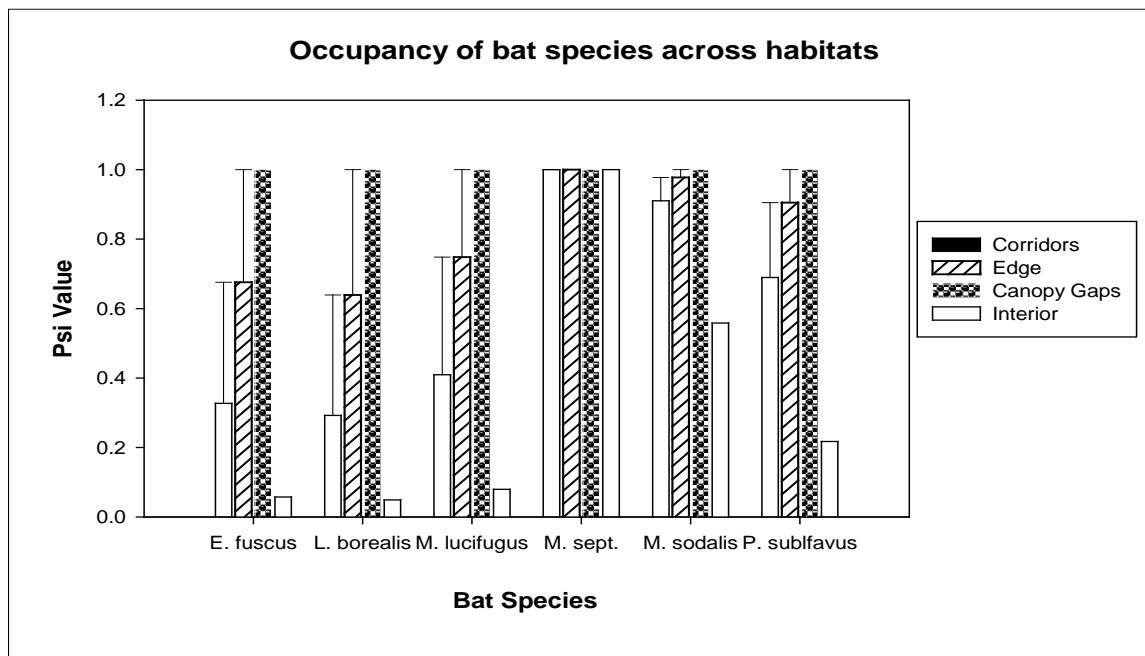


Figure 7. Occupancy of bat species in each habitat: corridors, forest edge, canopy gaps, and forest interior; where one is the highest occupancy.

## Discussion

*Bat Calls Detected*

Seven species of bats were detected, but two additional species, silver-haired bat and evening bat (*Nycticeius humeralis*), occur in this region of Indiana (Whitaker et al. 2007). Silver-haired and evening bats were not detected during the acoustic survey. During a concurrent survey with mist nets (Sheets et al. In Review) evening bats were not caught, and silver-haired bats were only caught during spring migration. Acoustic sampling began after the migration of silver-haired bats, so our failure to detect this species was expected and logical. In contrast, the evening bat does occur in the region, but the distribution is spotty and is most often found in lowland areas (Whitaker et al. 2007), which were not sampled.

Like every sampling method, bat detectors have their bias. In forests, clutter from vegetation, vertical vegetation layering, and call intensity, weather conditions, theft, vandalism, among others, may affect the accuracy, quantity, and quality of calls detected (Hayes 2000, Weller and Zabel 2002, Duchamp et al. 2006). This was controlled by directing or placing the bat detectors away from roads and heavily cluttered stands of vegetation. Vandalism or theft did not occur and were not an issue. On occasion, adverse weather conditions may have occurred, but were not frequent enough to affect call detection.

By their very nature, the acoustical differences between calls produced by different species can result in species-specific differences in detectability within different habitats. Unlike some previous studies (Yates and Muzika 2006, Loeb and O'Keefe 2006) I accounted for this difference by comparing detection probabilities across each habitat for each species. Detection probability was significantly lower ( $p < 0.05$ ) for northern and Indiana myotis within interior

forest, likely as a result of these higher-pitched calls being broken up by vegetation. Detection probability did not differ between habitats for other species (Table 4).

### *Habitats Occupied*

The predicted order of occupied habitats across all species combined was: corridor, forest edge, canopy gap, and forest interior. Even though the northern myotis had a high occupancy in all of the habitats, the rest of the species occupied canopy gaps the most followed by forest edge, corridors, and forest interior (Figure 7). Bats occupied canopy gaps the most because they are an uncluttered habitat surrounded by forest edge. Bats that cannot tolerate clutter spend most of their time foraging in canopy gaps (Hogburg et al. 2002, Putriquin and Barclay 2003, Owen et al. 2004). Forest edge is second in occupancy among species and is clutter free, but may not be occupied by some myotis species that roost and forage in the forest (Menzel et al 2001, Menzel et al. 2005a, Putriquin and Barclay 2003). Corridors are the third most occupied habitat, as in previous studies (Limpens et al. 1989). Timing of use suggests these are used primarily when bats commute to and from roosts, although some bats were present through the night. Forest interior, with the most clutter, is avoided by most bat species (Loeb and O'Keefe 2006) and thus is occupied least.

### *Timber Harvest Effects on Habitat Use*

Occupancy of habitats for each species can help us understand effects timber harvest management may have on foraging bats (Yates and Muzika 2006). Data from this survey supports the literature that each species uses different habitats due to varying morphological characteristics. Canopy gaps and edge habitats are used by bats more than cluttered interior forest. Using this information will determine if certain timber management treatments, in

creating or disturbing certain habitats, will positively or negatively affect bat species. Timber harvests will increase corridor, canopy gap, and edge habitats, and we anticipate that this will create foraging habitat for most species.

Roosting habitat is not represented in this data. Timber harvest may destroy roost sites but this should be minimal within large forested areas. Older forest stands where roosts are available situated or connected to open uncluttered foraging habitat will benefit most species of bats (Loeb and O'Keefe 2006).

### *Specific Bat Species*

As expected, big brown bats occupied canopy gaps and edges more than corridors and interior forest habitats. This bat forages in agricultural lands (Duchamp et al. 2004) and in uncluttered environments (Loeb and O'Keefe 2006). This species may commute, using corridors, into and out of Morgan-Monroe and Yellowwood state forests from anthropogenic roosts. Small clear cuts connected to non-forested areas will provide adequate foraging habitat for big brown bats.

Eastern red bats most occupied canopy gaps followed by edge, consistent with wing morphology that is specialized for habitats with minimal clutter (Elmore et al. 2004). Because they roost in foliage (Mager and Nelson 2001) within the forest, red bats characteristically exploited gaps within the forest. Corridors were likely used during commutes between foraging bouts and roosts. Yates and Muzika (2006) found that red bat occupancy rates were higher in stands with more open understory. Small clear and shelter-woods cuts, that reduce tree clutter, will provide foraging habitat for red bats.

The echolocation call (Arita and Fenton 1997) and medium wing loading (Broders et al. 2004) of little brown myotis suggest this species uses a moderately cluttered habitat and they are known to forage along edges (Hogburg et al. 2002) and over still water (Barclay and Brigham 1991), which was rare in the upland study area. A lack of still water for foraging and few anthropogenic roosts may explain the relative rarity of this species in Morgan-Monroe and Yellowwood state forests (Sheets et al. In Review). Little brown myotis like big brown bats may use corridors to commute from roosts outside the forest. This species will benefit from small clear, shelter-wood, and small group cuts near or connected to water.

The northern myotis, a clutter-adapted species, is considered to prefer continuous forests and older forest stands (Owen et al. 2003, Loeb and O'Keefe 2006), and could be negatively affected by timber harvests. Yates and Muzika (2006) found that northern myotis are not negatively affected by fragmentation. With timber harvests creating areas that are open or less cluttered, northern myotis, may prefer forest structured like Morgan-Monroe and Yellowwood state forests as of 2007 (30 to 80 years in age) which timber harvest regime was mostly single tree and small group selection cuts.

The Indiana myotis occupied canopy gaps and forest edges the most, which was expected. Corridors were also more occupied compared to other less-cluttered adapted species. The Indiana bat occupied forest interior more than other bats but use was low enough to suggest that this species prefers less cluttered habitats. Indiana myotis can tolerate some clutter, but are more often detected along forest edges, forest openings and corridors (Sparks et al. 2005, Brack in press). If Indiana bats have limited access to edges and canopy gaps they may be use more cluttered interior forests. Forest with timber management goals to increase low clutter habitats in conjunction with leaving mature tree stands, which provide roosts, will benefit this endangered

species. The absence of such habitats may explain its rarity at this site. With implantation of new timber harvests including clear cuts and shelter-wood cuts more suitable habitat will be created.

The eastern pipistrelle is considered a cluttered-adapted species (Menzel et al. 2005b), but it was most common in canopy gaps and was common in all habitat types suggesting it should perhaps be considered a habitat generalist (Loeb and O'Keefe 2006, Helms et al. Unpublished). Eastern pipistrelle will benefit from timber management that creates a variety of habitats, especially early successional habitat.

The hoary bat was only detected in corridors and edges and was not included in the occupancy model. Hoary bats echolocation calls and high wing loading suggest use of a clutter-free environment (Barclay et al. 1999). Corridors and edges are both relatively clutter free. Hoary bats may be more commonly found foraging above the forest canopy, but will benefit from small clear cuts within the forest.

These results provide some insight into the potential responses of these seven species of bats to forest management practices. Timber managers can use occupancy data as a tool to determine methods to successfully provide both forest products and high quality habitat for bats. To sustain the whole bat community in forests, timber management, must employ multiple harvest methods creating habitats at many successional stages to insure that all bat species will continue be a part of the forest community. As the fungal disease, White Nose Syndrome (WNS) approaches the Midwest; there will be an added emphasis on managing quality habitats for all bat species.

## REFERENCES

- Anthony, E.L.P. and T.H. Kunz. 1977. Feeding strategies of the little brown bat, *Myotis lucifugus*, in southern New Hampshire. *Ecology* 58:775-786.
- Arita, H.T. and M.B. Fenton. 1997. Flight and echolocation in the ecology and evolution of bats. *Trends Ecological Evolution* 12:53-58.
- Audubon, J.J. and J. Bachman, 1842. Descriptions of new species of quadrupeds inhabiting North America. *Journal of the Academy of Natural Sciences of Philadelphia* 8:284.
- Barbour, R.W. and W.H. Davis. 1969. *Bats of America*. University Kentucky Press, Lexington, Kentucky 286 pp.
- Barclay, R.M.R. and Brigham, R.M. 1991. Prey detection, dietary niche breadth, and body size in bats: why are aerial insectivorous bats so small? *American Naturalist* 137:693-703.
- Barclay, R.M.R. and Brigham, R.M. (eds.). 1996. *Bat and forests symposium, 19-21 October 1995, Victoria, B.C.* British Columbia Ministry of Forests, Victoria, B. C.
- Barclay, R.M.R., P.A. Faure, and D.R. Farr. 1988. Roosting behavior and roost selection by migrating silver-haired bats (*Lasionycteris noctivagans*). *Journal of Mammalogy* 69:821-825.
- Barclay, R.M.R. and A. Kurta. 2007. Ecology and behavior of bats roosting in tree cavities and under bark. *In* Lacki, M.J., J.P. Hayes, and A. Kurta (eds.). *Conservation and management of forests bats*. Johns Hopkins University, Baltimore, Maryland, USA.

- Barclay, R.M.R., J.H. Fullard, and D.S. Jacobs. 1999. Variation in the echolocation calls of the hoary bat (*Lasiurus cinereus*): influence of body size, habitat structure, and geographic location. *Canadian Journal of Zoology* 77:530-534.
- Bartsch, P. 1956. An interesting catch. *Journal of Mammalogy* 37:111.
- Beer, J.R. 1956. A record of a silver-haired bat in a cave. *Journal of Mammalogy* 37:282.
- Belwood, J.J. 1979. Feeding ecology of the Indiana bat community with emphasis on the endangered Indiana bat, *Myotis sodalis*. M.S. thesis, University of Florida, Gainesville, Florida.
- Betts, B.J. 1998. Roosts used by maternity colonies of silver-haired bats in north-eastern Oregon. *Journal of Mammalogy* 79:643-650
- Blehart D.S., A.C. Hicks, M. Behr, C.U. Meteyer, B.M. Berlowski-Zier, E.L. Buckles, J.T.H. Coleman, S.R. Darling, A. Gargas, R. Niver, J.C. Okoniewski, R.J. Rudd, W.B. Stone. 2009. Bat white-nose syndrome: an emerging fungal pathogen? *Science* 323:227.
- Boyles, J.G. and D.P. Aubrey. 2005. Managing forests with prescribed fire; Implications for a cavity-dwelling bat species. *Forest Ecology and Management* 222:108-115.
- Boyles, J.G., B.M. Mormann, and L.W. Robbins. 2005. Use of underground winter roost by a male evening bat (*Nycticeius humeralis*). *Southeastern Naturalist* 4:375-377.
- Brack, V., Jr. 1983. The nonhibernating ecology of bats in Indiana with emphasis on the endangered Indiana bat (*Myotis sodalis*). MS thesis. Purdue University 279pp.
- Brack, V., Jr. 2009. Summer bats of Potter and McKean counties, Pennsylvania and adjacent Cattaraugus County, New York. *Pennsylvania Academy of Science* 83:17-23.
- Brack, V., Jr. Unpublished data.



- Brack, V., Jr. and J.C. Carter. 1985. Use of an underground burrow by *Lasionycteris*. Bat Research News 26:28-29.
- Brack, V., Jr. and J.A. Hawkings. In Litt. Habitat conservation plan: 2004 summer mist netting and telemetry study of maternity colonies of the Indiana bat (*Myotis sodalis*). Indiana DNR HCP technical reports pp 1-27.
- Brack, V., Jr. and R.K LaVal. 1985. Food habits of the Indiana bat in Missouri. Journal of Mammalogy 66:308-315.
- Brack, V., Jr. and R.K. LaVal. 2006. The diet of the gray myotis (*Myotis grisescens*): variability and consistency, opportunism and selectivity. Journal of Mammalogy 87:7-18.
- Brack, V., Jr. and J.O. Whitaker Jr. 2001. Foods of the northern myotis, *Myotis septentrionalis*, from Missouri and Indiana, with notes on foraging. Acta Chiropterologica 3:203-210.
- Brack, V., Jr. and J.O. Whitaker Jr. 2004. Bats of the Naval Surface Warfare Center at Crane, Indiana. Proceedings of the Indiana Academy of Science 113:66-75.
- Brack, V., Jr. and J.O. Whitaker Jr. 2006. The Indiana myotis (*Myotis sodalis*) on an anthropogenic landscape: Newport Chemical Depot, Vermillion County, Indiana. Proceedings of the Indiana Academy of Science 115:44-52.
- Brack, V., Jr., R.E. Mumford, and V.R. Holmes. 1984. The gray bat (*Myotis grisescens*) in Indiana. American Midland Naturalist 111:205.
- Brack, V. Jr., J.O. Whitaker Jr. and S.E. Pruitt. 2004. Bats of Hoosier National Forest. Proceedings of the Indiana Academy of Science 113:76-86.
- Brigham, R.M. and M.B. Fenton. 1986. The influence of roost closure on the roosting and foraging behavior of *Eptesicus fuscus* (Chiroptera: Vespertilionidae). Canadian Journal of Zoology 64:1128-1133.

- Brigham, R.M., S.D. Grindal, M.C. Firman, and J.L. Morissette. 1997. The influence of structural clutter on activity patterns of insectivorous bats. *Canadian Journal of Zoology* 75:131-136.
- Britzke, E.R. 2003. Use of ultrasonic detectors for acoustic identification and study of bat ecology in the eastern United States. Dissertation, Tennessee Technological University.
- Britzke, E.R. and K.L. Murray. 2000. A quantitative method for selection of identifiable search-phase calls using the Anabat system. *Bat Res. News* 41:33–36.
- Broders, H.G., C.S. Findlay and L. Zheng. 2004. Effects of clutter on echolocation call structure of *Myotis septentrionalis* and *M. lucifugus*. *Journal of Mammalogy* 85:273-281.
- Brooks, R.T. and W.M. Ford. 2005. Introduction to the special section-bat habitat use in Eastern Temperate Forests: site, stand, landscape effects. *Journal of Wildlife Management* 70:1117-1173.
- Brown, R.J. and V. Brack Jr. 2003. An unusually productive net site over an upland road used as a travel corridor. *Bat Res. News* 44:187-188.
- Brown, L.N. and C.K. Brown. 1993. First record of the eastern big-eared bat (*Plecotus rafinesquii*) in Southern Florida. *Florida Science* 56:63
- Buford, L.S. and M.J. Lacki. 1995. Habitat use by *Corynorhinus townsendii virginianus* in the Daniel Boone National Forest. *American Midland Naturalist* 134:340-345.
- Callahan, E.V., R.D. Drobney, and R.L. Clawson. 1997. Selection of summer roosting sites by Indiana bats (*Myotis sodalis*) in Missouri. *Journal of Mammalogy* 78:818-825.

- Carter, T.C. and G.A. Feldhammer. 2006. Roost tree use by maternity colonies of Indiana bats and northern long-eared bats in southern Illinois. *Forest Ecology and Management* 222:108-115.
- Carter, T.C., W.M. Ford, and M.A. Mezel. 2000. Fire and bats in the Southeast and Mid-Atlantic: more questions than answers? Pp.139-143 *In* Ford, W.M., K.R. Russell, C.E. Moorman (eds.). *The Role of Fire for Nongame Wildlife Management and Community Restoration: Traditional Uses and New Directions*. United States Department of Agriculture, General Technical Report NE.
- Clark, B.S., D.M. Leslie, Jr., and T.S. Carter. 1993. Foraging activity of adult female Ozark big-eared bats (*Plecotus townsendii ingens*) in summer. *Journal of Mammalogy* 74:422-427.
- Clark, M.K. 1991. Foraging ecology of the Rafinesque's big-eared bat (*Plecotus rafinesquii*) in North Carolina. *Bat Res. News* 32:68
- Cope, J. B., J. O. Whitaker, Jr., and S.L. Gummer. 1991. Duration of bat colonies in Indiana. *Proceedings of the Indiana Academy of Science* 99:199-201.
- Crampton, L.H., and R. M.R. Barclay. 1998. Selection of roosting and foraging habitat by bats in different -aged mixed hardwoods stands. *Conservation Biology*, 12:1347-1358
- Cryan, P.M., M.A. Bogan, and G.M. Yanega. 2001. Roosting habits of four bat species in the Black Hills, South Dakota. *Acta Chiroptologica*, 3:43-52
- Duchamp, J.E., D.W. Sparks, and J.O. Whitaker Jr. 2004. Foraging-habitat selection by bats at an urban-rural interface: comparison of a successful and a less successful species. *Canadian Journal of Zoology* 82:1157-1164.

- Duchamp, J.E., M. Yates, R. Muzika, and R.K. Swihart. 2006. Estimating probabilities of detection for bat echolocation calls: An application of the double observer method. *Wildlife Society Bulletin* 34:408-412.
- Elmore, L.W., D.A. Miller, and F.J. Vilella. 2004. Selection of diurnal roosts by red bats (*Lasiurus borealis*) in an intensively managed pine landscape in Mississippi. *Forest Ecology and Management* 199:11-20.
- Elmore, L.W., D.A. Miller, and F.J. Vilella. 2005. Foraging area size and habitat use by red bats (*Lasiurus borealis*) in an intensively managed pine landscape in Mississippi. *American Midland Naturalist* 153:405-417.
- Fellers, G.M. and E.D. Pierson. 2002. Habitat use and foraging behavior of Townsend's big-eared bat (*Corynorhinus townsendii*) in coastal California. *Journal of Mammalogy* 83:167-177.
- Fisher, J.T. and L. Wilkinson. 2005. The response of mammals to forest fire and timber harvest in the North American boreal forest. *Mammal Review* 35:51-81.
- Foster, R.W. and A. Kurta. 1999. Roosting ecology of the northern bat (*Myotis septentrionalis*) and comparisons with the endangered Indiana bat (*Myotis sodalis*). *Journal of Mammalogy*, 80:659-672.
- Gooding, G., and J.R. Langford. 2004. Characteristics of tree roosts of Rafinesque's big-eared bat and southeastern bat in northeastern Louisiana. *Southwestern Naturalist*, 49:61-67.
- Graham, R.E. 1966. Observations of the roosting habits of the big-eared bat, *Plecotus townsendii*, in California limestone caves. *Cave notes* 8:17-22.

- Grindal, S.D. 1996. Habitat use by bats in fragmented forests. Pp. 260 – 272 *In* R.M.R. Barclay and R.M. Brigham (eds.). Bats and Forest Symposium October 19 – 21, 1995 Victoria, British Columbia, Canada. Research Branch, British Columbia Ministry of Forests, Victoria, Canada 292 pp.
- Gorresen, P.M., A.C. Miles, C.M. Todd, F.J. Bonaccorso, and T.J. Weller. 2008. Assessing bat detectability and occupancy with multiple automated echolocation detectors. *Journal of Mammalogy* 89:11-17.
- Gumbert, M.W., J.M. O'Keefe, and J.R. MacGregor. 2002. Roost fidelity in Kentucky. Pp.143-152 *In* Kurta, A., J. Kennedy (eds.). The Indiana Bat Conservation International, Austin, TX.
- Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. *Journal of Mammalogy* 78:514-524.
- Hayes, J.P. 2000. Assumptions and practical considerations in the design and interpretation of echolocation-monitoring studies. *Acta Chiropterologica* 225-236.
- Hayward, B.J. 1970. The natural history of cave bat *Myotis velifer*. *Res. Sci. Western New Mexico Univ.* 1:1-74.
- Helms, J.S., D.W. Sparks, and J.O. Whitaker, Jr. Unpublished. A little bat and a big city: nocturnal behavior of eastern pipistrelle (*Perimyotis subflavus*) near Indianapolis Airport.
- Hogburg, L.K., K.J. Patriquin, and R.M.R. Barclay. 2002. Use by bats of patches of residual trees in logged areas of the boreal forest. *American Midland Naturalist* 148:282-288.
- Humphrey, S.R., A.R. Richter, and J.B. Cope. 1977. Summer habitat and ecology of the endangered Indiana bat (*Myotis sodalis*). *Journal of Mammalogy* 58:334-346.

- Hurst, T.E. and M.J. Lacki. 1999. Roost selection, population size, and habitat use by a colony of Rafinesque's big-eared bats (*Corynorhinus rafinesquii*). *American Midland Naturalist* 142:363-371.
- Hutchinson, J.T. and M.J. Lacki. 1999. Foraging behavior and habitat use of red bats in mixed mesophytic forests of the Cumberland Plateau, Kentucky. Pp. 171-177 *In* Stringer, J. W and D. L. Loftis (eds.). 12<sup>th</sup> Central Hardwood Forest Conference, U. S. Forest Service, South. Experiment Stat., Asheville, North Carolina.
- Kiser, J.D. 2005. The Indiana bat: habitat needs and forest management. Pp. 22 *In* Miller, B.K. (ed.). *Managing Wildlife for Sustainable Forest*, Indianapolis, IN.
- Kiser, J. and J.R. MacGregor. 2005. Indiana bat (*Myotis sodalis*) mist net surveys for coal mining activities. Pp. 45-62 *In* Vories, K. C. and A. Harrington (eds.). *Indiana Bats and Coal Mining, A Technical Interactive Forum*. Office of Surface Mining, U.S. Department of the Interior, Alton, Illinois.
- Krusac, D.L. and S.R. Mighton. 2005. The Indiana bat: habitat needs and forest management. *In* Kurta, A and J. Kennedy. (eds.). *The Indiana Bat: Biology and Management of an Endangered Species* pp. 55-65.
- Kunz, T.H. R.A. Martin. 1982. *Plecotus townsendii*. *Mammalian Species* 175:1-6.
- Kurta, A. 2005. Roosting ecology and behavior of Indiana Bats (*Myotis sodalis*) in summer. *In* Vories, K.C. and A. Harrington (eds.). *Proceeding of the Indiana bat and coal: A Technical Interactive Forum* Office of Surface Mining, U.S. Department of the Interior, Alton, IL.
- Kurta, A and J. Kennedy (eds.). 2002. *The Indiana Bat: Biology and Management of an Endangered Species* 253 pp.

- Lacki, M.J. and J.H. Schwierjohann. 2001. Day-roost characteristics of northern bats in mixed mesophytic forest. *Journal of Wildlife Management* 65:482.
- Lacki, M.J., J.P. Hayes, and A. Kurta. 2007. *Bats in forests*. The John Hopkins University Press, Baltimore, Maryland 329pp.
- Lacki, M.J., D.R. Cox, L.E. Dodd, M.B. Dickinson. 2009. Response of northern bats (*Myotis septentrionalis*) to prescribed fires in Eastern Kentucky forests. *Journal of Mammalogy* 90:1165-1175.
- LaVal, R.K., R.L. Clawson, M.L. LaVal, and W. Caire. 1977. Foraging behavior and nocturnal activity patterns of Missouri bats, with emphasis on endangered species (*Myotis grisescens* and *Myotis sodalis*). *Journal of Mammalogy* 58:592-599.
- LaVal, R.K. and M.L. LaVal. 1980. Ecological studies and management of Missouri bats, with emphasis on cave-dwelling species. Missouri Department of Conservation Terrestrial Series 8:1-53.
- Lewis, J.J. 1996. Inventory of the subterranean biota threatened by the urbanization of Clark and Floyd counties, IN. Pp. 1-7 *In* IDNR Division of Fish and Wildlife Non-game and Endangered Wildlife Program.
- Limpens, H.J.G.A., W. Helmer, A. Van Winden, K. Mostert. 1989. Bats (Chiroptera) and linear landscape elements: a review of our present knowledge of the importance of linear landscape elements to bats. *Lutra* 32:1-20.
- Loeb, S.C. and J.M. O'Keefe. 2006. Habitat use by forest bats in South Carolina in relation to local, stand, and landscape characteristics. *Journal of Wildlife Management* 70:1210-1218.
- MacArthur, R.H. 1972. *Geographical Ecology*. Harper and Row, New York, New York.

- Mager, K.J. and J.A. Nelson. 2001. Roost-site selection by Eastern red bats (*Lasiurus borealis*). American Midland Naturalist 145:120-126.
- MacGregor, J.R. and J.D. Kiser. 1998. Recent reproductive records for the Eastern small-footed bat (*Myotis leibii*) in Kentucky with notes on a maternity colony located in a concrete bridge. Bat Research News 39:175-176
- Menzel, M.A., T.C. Carter, B.L. Mitchell, L.R. Jablonowski, B.R. Chapman, J. Learn. 2000. Prey selection by a maternity colony of big brown bats (*Eptesicus fuscus*) in the southeastern United States. Florida Scientist 63:232-241.
- Menzel, M.A., J.M. Menzel, T.C. Carter, W.M. Ford, and J.W. Edwards (eds.). 2001. Review of the forest habitat relationships of the Indiana bat (*Myotis sodalis*). United States Department of Agriculture, General Technical Report NE 284 pp.
- Menzel, M.A., S.F. Owen, W.M. Ford, J. W. Edwards, P.B. Wood, B.R. Chapman and K.V. Miller. 2002b. Roost tree selection by northern long-eared bat (*Myotis septentrionalis*) maternity colonies in an industrial forest of the central Appalachian Mountains. Forest Ecology and Management 155:107-114.
- Menzel, J.M., W.M. Ford, M.A. Menzel, T.C. Carter, J.E. Gardner, J.D. Garner, and J.E. Hoffman. 2005a. Summer habitat use and home-range analysis of the endangered Indiana bat. Journal of Wildlife Management 69:430-436.
- Menzel, J.M., M.A. Menzel Jr., J.C. Kilgo, W.M. Ford, J.W. Edwards, and G.F. McCracken. 2005b. Effect of habitat and foraging height on bat activity in coastal plain of South Carolina. Journal of Wildlife Management 69:235-245.
- Miller B.W. 2001. A method for detecting relative activity of free flying bats using a new activity index for acoustic monitoring. Acta Chiropterologica 1:105-112.



- Miller, D.A. 2003. Species diversity, reproduction, and sex ratios of bats in managed pine forest landscapes of Mississippi. *Southeastern Naturalist* 2:59-72.
- Moorsman P.R., Jr., H.H. Thomas, and J.P. Veilleux. 2007. Foot habits of eastern small-footed myotis (*Myotis leibii*) in New Hampshire. *American Midland Naturalist* 158:354-360.
- Mumford, R.E. and J.O. Whitaker, Jr. 1982. *Mammals of Indiana*. Indiana University Press, Bloomington, Indiana. 537pp.
- Murray, K.L., E.R. Britzke, and L.W. Robbins. 2001. Variation in search-phase calls of bats. *Journal of Mammalogy* 82:728-737.
- Novakowski, N.S. 1956. Additional records of bats in Saskatchewan. *Canadian Field-Naturalist* 70:142.
- Owen, S.F., M.A. Menzel, J.W. Edwards, W.M. Ford, B.R. Chapman, J.W. Edwards, and P.B. Wood. 2003. Home-range size and habitat use by the Northern Myotis (*Myotis septentrionalis*). *American Midland Naturalist* 150:352-359.
- Owen, S.F., M.A. Menzel, J.W. Edwards, W.M. Ford, J.M. Menzel, B.R. Chapman, P.B. Wood, and K.V. Miller. 2004. Bat activity in harvested and intact forest stands in the Allegheny Mountains. *North Journal of Applied Forestry* 21:154-159.
- Parsons, H.I., D.A. Smith, and R.F. Whittam. 1986. Maternity colonies of silver-haired bats (*Lasiycteris noctivagans*) in Ontario and Saskatchewan. *Journal of Mammalogy* 67:598-600.
- Perry, R.W. and R.E. Thill. 2007. Roost characteristics of hoary bats in Arkansas. *American Midland Naturalist* 158:132-138.
- Putriquin, K.J. and R.M.R. Barclay. 2003. Foraging by bats in cleared, thinned, and unharvested boreal forest. *Journal of Applied Ecology* 40:646-657.

- Sasse, D.B. and P.J. Perkins. 1996. Summer roosting ecology of northern long-eared myotis (*Myotis septentrionalis*) in the White Mountain National Forest. Pp. 182-192 In Barclay, R.M.R. and R.M. Brigham (eds.). Bats and Forest Symposium.
- Sheets, J.J., D.W. Sparks, V. Brack, Jr., J.O. Whitaker, Jr. In Review. Bats of Yellowwood and Morgan-Monroe state forests before timber harvest. Proceedings of the Indiana Academy of Science.
- Sheldon S. 2007. Resource Management Guide.  
<http://www.in.gov/dnr/forestry/pdfs/MorganMonroeC6T10.pdf>.
- Sparks, D.W., J.A. Laborda, and J.O. Whitaker Jr. 1998. Bats of the Indianapolis International Airport as compared to a more rural community of bats at Prairie Creek. Proceedings of the Indiana Academy of Science 107:171-179.
- Sparks, D.W., K.J. Roberts, and C. Jones. 2000. Vertebrate predators on bats in North America North of Mexico. Pp: 229-241 In J. R. Choate (ed.). Reflections of a naturalist: papers honoring professor Eugene D. Fleharty, Fort Hays Studies, Special Issue 1: 1-241.
- Sparks, D.W., R.M. Ritzi, D.E. Duchamp, and J.O. Whitaker Jr. 2005a. Foraging habitat of the Indiana bat (*Myotis sodalis*) of an urban-rural interface. Journal of Mammalogy 86:713-718.
- Sparks, D.W., C.M. Ritzi, and B.L. Everson. 2005b. Nocturnal behavior and roosting ecology of a juvenile (*Lasiurus cinereus*) near Indianapolis, Indiana. Proceedings of the Indiana Academy of Science 114:70-72.

- Sparks, D.W., V. Brack, Jr., J.O. Whitaker, Jr., and R. Lotspeich. 2009. Reconciliation ecology and the Indiana Bat at Indianapolis International Airport, Chapter 3. *In* P. B. Laraue and M. E. Castille (eds.). Airports: Performance, Risks, and Problems, Nova Science Publishers, Inc., Hauppauge, New York.
- Tibbles, A.E. and A. Kurta. 2003. Bat activity is low in thinned and unthinned stands of red pine. *Can. J. For. Res.* 33:2436-2442.
- Tuttle, M.D. 1976a. Population ecology of the grey bat (*Myotis grisescens*): factors influencing growth and survival of newly volant young. *Ecology* 57:587-595.
- Tuttle, M.D. and L.R. Heaney. 1974. Maternity habits of (*Myotis leibii*) in South Dakota. *Bull S. Cal. Acad. Sci.* 73:80-83.
- Tuttle, N.M., D.P. Benson, and D.W. Sparks. 2006. Diet of *Myotis sodalis* (Indiana bat) at an Urban/Rural Interface. *Northeastern Naturalist* 13:435-442.
- Veilleux, J.P., J.O. Whitaker, Jr., and S.L. Veilleux. 2003. Tree roosting ecology of reproductive female eastern pipistrelles, *Pipistrellus subflavus*, in Indiana. *Journal of Mammalogy* 84: 1068-1075.
- Walters, B.L., C.M. Ritzi, D.W. Sparks, and J.O. Whitaker Jr. 2006. Foraging behavior of Eastern red bats (*Lasiurus borealis*) at an urban-rural interface. *American Midland Naturalist* 157:365-373.
- Watkins, L.C. 1972. *Nycticeius humeralis*. Mammalian Species No. 23. American Society of Mammalogist 4 pp.
- Weller, T.J. and C.J. Zabel. 2002. Variation in bat detections due to detector orientation in a forest. *Wildlife Society Bulletin* 30:922-930.

- Wethington, T.A., D.M. Leslie, M.S. Gregory, and M.K. Wethington. 1996. Vegetative structure and land use relative to cave selection by endangered Ozark big-eared bats (*Corynorhinus townsendii ingenus*). *Southwestern Naturalist* 42:177-181.
- Whitaker, J.O., Jr. 1972. Food habits of bats from Indiana. *Canada. J. Zool.* 50: 877-883.
- Whitaker, J.O., Jr. 1996. *National Audubon Society Field Guide to North American Mammals*. Revised Ed. Chanticleer Press. Alfred A. Knopf. New York, Toronto. 937 pp.
- Whitaker, J.O., Jr. 1997. Bats of Prarie Creek. *Proceedings of the Indiana Academy of Science* 105:87-94.
- Whitaker, J.O., Jr. 1998. Life history and roost switching in six summer colonies of eastern pipistrelles in buildings. *Journal of Mammalogy* 79: 651-659.
- Whitaker, J.O., Jr. and S.L. Gummer. 1992. Hibernation of the big brown bat, *Eptesicus fuscus*, in buildings. *Journal of Mammalogy* 73:312-316.
- Whitaker, J.O., Jr. and S.L. Gummer. 2003. Current status of the evening bat, *Nycticeius humeralis*, in Indiana. *Proceedings of the Indiana Academy of Science* 112:55-60.
- Whitaker, J.O., Jr. and W.J. Hamilton, Jr. 1998. *Mammals of the Eastern United States*. Cornell University Press, Ithaca, New York 583 pp.
- Whitaker, J.O., Jr. and D.W. Sparks. 2008. Roosts of Indiana myotis at Indianapolis International Airport. *Proceedings of the Indiana Academy of Science*, 117:193-202.
- Whitaker, J.O., Jr., C. Maser and S.P. Cross. 1981a. Foods of Oregon silver-haired bats, *Lasionycteris noctivagans*. *Northwest Science* 55: 75-77.
- Whitaker, J.O., Jr., C. Maser and S. Cross. 1981b. Food habits of eastern Oregon bats, based on stomach and scat analyses. *Northwest Science* 55: 281-292.

- Whitaker, J.O., Jr., D.W. Sparks, and V. Brack Jr. 2004. Bats of the Indianapolis Airport Area, 1991-2001. *Proceedings of the Indiana Academy of Science* 113:151-161.
- Whitaker, J.O., Jr., D.W. Sparks, and V. Brack, Jr. 2006. Use of artificial roost structures by bats at the Indianapolis International Airport. *Environmental Management* 38:28-36.
- Whitaker, J.O., Jr., C.L. Gummer, A. Howard, W.A. Ulrey, and V. Brack, Jr. 2005. Bats of Camp Atterbury in south central Indiana. *Proceedings of the Indiana Academy of Science* 114:216-223.
- Whitaker, J.O., Jr., V. Brack, Jr., D.W. Sparks, J.B. Cope, and S. Johnson. 2007. Bats of Indiana. Indiana State University Center for North American Bat Research and Conservation, Terre Haute, Indiana 59 pp.
- Willis, C.K.R. and R.M. Brigham. 2004. Roost switching, roost sharing and social cohesion: forest-dwelling big brown bats, *Eptesicus fuscus*, conform to the fission-fusion model. *Animal Behaviour* 68:495-505.
- Yates, M.D. and R.M. Muzika. 2007. Effect of forest structure and fragmentation on site occupancy of bat species in Missouri Ozark Forests. *Journal of Wildlife Management* 70:1238-1248.
- Zimmerman, G.S. and W.E. Glanz. 2000. Habitat use by bats in eastern Maine. *Journal of Wildlife Management* 64:1032-10.
- Zinn, T.L., and S.R. Humphrey. 1981. Seasonal food resources and prey selection of the southeastern brown bat (*Myotis austroripius*) in Florida. *Florida Scientist* 44:81-90.

## APPENDIX A: HARDWOOD ECOSYSTEM EXPERIMENT: AN OVERVIEW

### Goals and Partnerships

The main goal of the Hardwood Ecosystem Experiment (HEE) is to determine the ecological and social impacts of forest harvest and other silvicultural manipulations on public and private lands in Indiana as well as the rest of the Central Hardwoods Region. This effort has 4 parts:

- 1) Develop a proven system of forest management prescriptions to maintain communities dominated by oak (*Quercus* sp.) and hickory (*Carya* sp.) species and other desired populations of native plants and animals.
- 2) Develop an understanding of the response of targeted native wildlife and plant species to forest management practices in order to help mitigate potential negative effects on species of special concern especially the federally endangered Indiana bat (*Myotis sodalis*).
- 3) Assess public attitudes towards forest management by developing techniques to educate the general public and private landowners about the benefits of land use practices such as timber harvest.
- 4) Identify direct and indirect benefits of specific forest management practices to local and regional communities and its impact in community development.

### Proposed Forest Manipulations (selected by HEE project leaders)

Nine management units (MU) of 900-acres (about 405 ha) will be manipulated within Morgan-Monroe and Yellowwood State Forests. Each of these includes a 200-acre (81 ha) sampling unit (SU) surrounded by 700-acres (284 ha) of buffer. In each SU there are 0, 4, or 8 treatment areas (TA). Each SU will receive only 1 of 3 types of forest management starting in summer 2008: even aged cutting (4 TAs), uneven-aged cutting (8 TAs), or control (0 TAs). Single-tree selection will also be included in the uneven-aged SUs outside of the TAs. Single-tree and group selection will continue in the buffer surrounding both control and experimental sampling units. All forest manipulations are subject to change. Each MU will be on a 100-year rotation with new cuts made every 20 years.

Even-aged TAs site selection will be stratified by slope with 6 harvest sites centered at least 900m apart with 3 on south or west slopes and 3 on north or east slopes. IDNR employees chose 2 locations per slope for harvest. Each even-aged SU will receive 2 shelter-wood (1 north or east slope and 1 south or west slope) and 2 clear-cut (1 north or east slope and 1 south or west slope) treatments in 10 acre (4 ha) patches. All trees in the TA will be removed during clear-cuts, whereas a few high quality trees will be left behind during shelter-woods to provide a source of seeds and protection during regeneration (overstory cut 5-10 years).

In uneven-aged SUs, eight TAs will be cut: two 5-acre, (2 ha), two 3-acre, (1.2 ha), and four 1-acre (0.4 ha) openings (for a total of 20 acres (7.2 ha) of group openings for each uneven-aged research core) within which all overstory trees will be removed. Openings will still be paired based upon aspect. The area within the SU, but outside the TAs will receive single-tree selection.

Control TA site selection consists of 4 points randomly placed in each management unit with 2 points each on both northeast and southwest slopes and separated by at least 900m.

Control TAs will not be harvested nor will the understory be manipulated.

#### Basic Techniques for Sampling Bats

Bats were sampled using mist nets bat detectors. I sampled at 2 sites in each of the 9 SUs during a 15 May -15 August window each year. At each site 4 multi-tiered mist-net sets (Avinet, Inc. Dryden, New York) were arranged to maximize bat captures, often across travel corridors, such as logging roads (Brown and Brack 2003). These sites were netted twice per year on non-consecutive nights, producing 144 net nights of sampling per year. Mist nets were set up by nightfall and kept in place for 5 hours. Netting was delayed during rain and resumed when it stopped or cancelled if the rain persisted or temperatures fell below 10°C. Data collected on captured bats included species, sex, reproductive condition, right forearm length, weight, and age (juvenile or adult). Each bat received a uniquely numbered band to allow long-term identification.

Anabat II bat detectors were placed in 4 treatment areas of each SU during 15 May -15 August in 2007 and 2008. Twelve Anabat II bat detectors and Zero Crossing Analysis Interface Modules (ZCAIMs, Titley Electronics, Ballina, New South Wales, Australia: Detectors hereafter) were placed in the TAs. Detectors were set out 1 night early and 1 night late in the season. In even-aged and control SUs the 4 TAs were all sampled but only 4 of the 8 uneven-aged plots were randomly chosen for sampling. Each detector was placed 1 m above ground on a stand (Duchamp et al. 2006). Detectors were aligned on a random azimuth selected from a random numbers table. Three detectors were placed at each TA: one detector inside, one adjacent, and one outside the TAs. Because timber harvest had not yet occurred, all of these



detectors were in interior forest for a total of 216 samples of such habitat. Bat calls were filtered using ANALOOK (version 1.6, Titley Electronics).